NEW ZEALAND PRACTICAL HANDBOOKS.

# SOILS & MANURES
# IN NEW ZEALAND

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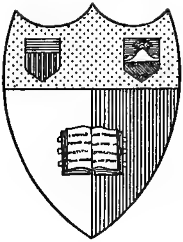

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# SOILS AND MANURES IN NEW ZEALAND

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Harvesting in Canterbury.

# SOILS AND MANURES
# IN NEW ZEALAND

BY

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# PREFACE.

This little book has been written for the practical farmer; hence the use of unfamiliar technical terms has been avoided as far as possible. No attempt has been made to lay down rules for the management of soils or for the use of manures. What has been attempted is to acquaint the reader with the more important truths and general principles regarding these things, in the hope that if these are assimilated the farmer, who is on the spot and knows the local conditions, will be able to determine for himself the proper procedure in his own individual case. In agriculture, as in other callings, that man is most likely to succeed whose mind is well stored with solid facts, and whose fertile brain is productive of ideas, than he who blindly follows "rules of thumb."

I have made free use of the standard works on Soils and Manures, most of which are mentioned after the various chapters as suitable for further reference. Finally, I desire to express my thanks to Dr. Reakes, Director-General of Agriculture, who most kindly lent me many of the blocks used as illustrations.

L.J.W.

*Lincoln, 1919.*

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# Soils & Manures in New Zealand.

## CHAPTER I.

## THE ABODE OF THE PLANT.

Just as the healthy development of a little child depends on the efficiency with which the necessaries of its nutrition, warmth, and general comfort are provided in its home, so also the growth of the plant depends entirely on the degree of completeness with which its demands at all stages for food, warmth, moisture, sunshine, absence of winds, and so on, are satisfied. Of these conditions the first three, namely, food-supply, warmth, and moisture, depend to a very large extent upon the soil in which the plant lives, and the relationship of plant to soil is, therefore, of an exceedingly intimate nature. As a matter of fact the soil is not a dead inert thing, not a mere mixture of sand, silt, and clay; but besides these constituents are organic matter and humus, water, air, carbonate of lime, and last, but not least, a dense population of living organisms, and each of these components plays its own part in determining the suitability of the soil as the abode of the plant.

Soils are derived partly from rocks and partly from vegetation by disintegration and decomposition. The chief agents at work are alternate freezing and thawing, heating and cooling; running and percolating water; the atmosphere; stress of rain and hail; the action of growing roots; and so on. On the rock detritus so produced lowly plants such as mosses and lichens grow, which by their death and decay add the organic matter and humus necessary for the prosperity of higher plants. So the decay of each generation improves the soil and makes possible the growth of still higher forms of plant life. The process is slow, but anyone who observes the sand on beach or river-bed worn from the larger stones, or who recalls how rapidly the remains of plants and animals—even the hard bone—decays in the soil, will realise how potent are the destructive agents.

## Mechanical Analysis.

In studying a soil in the laboratory it is usual to separate some of its components from one another, and such a process is called a mechanical analysis. A sample is washed with weak acid, and afterwards by ammonia, and then rubbed gently in a dish, by which process the particles of soil are freed from one another, so that, partly by means of sieves, and partly by stirring the soil in water, when the particles settle down in order according to their size and weight, the whole sample can be graded according to size into fractions. In order to be able to compare two soils on the basis of such an analysis it is necessary that the method of treatment of the two should be the same. For that reason British agriculturists have adopted a method which separates the soil into particles of the size shown in the table, and to which the names shown in the first column are applied.

| | Diameter in mms.* | | |
|---|---|---|---|
| | Maximum. | Minimum | |
| 1. Stones and gravel | — | 3·0 | Separated by sifting. |
| 2. Fine gravel | 3·0 | 1·0 | |
| 3. Coarse sand | 1·0 | 0·2 | |
| 4. Fine sand | 0·2 | 0·04 | Separated by subsidence. |
| 5. Silt | 0·04 | 0·01 | |
| 6. Fine silt | 0·01 | 0·002 | |
| 7. Clay | 0·002 | — | |

*1mm.=·039 inches.

It should be clearly understood that the main difference between these fractions is one of size only, and not necessarily of chemical composition.

The practical man has in mind the relative amounts of these constituents and the effects they produce on the general character of the soil when he describes a soil as light, medium, or heavy land. The term texture is frequently employed in the same sense; a soil is said to have an open or light texture when it is free-working and easily cultivated, and a close, stiff, or heavy texture when the opposite is the case. We shall now discuss the effects on soil texture of the various constituents listed above; but, in passing, it must be mentioned that the organic matter also has a profound effect in this connection, as will be explained in due course.

1. *Fine Gravel.*—In most cultivated soils in New Zealand this fraction is not present to any great extent; the average of samples is a few per cent. Its influence on texture is accordingly not very important.

2. *Coarse Sand.*—This is one of the most important constituents in that its effect is the reverse of that of clay; its presence makes a soil more friable, and tends to alleviate the heaviness caused by excess of the finer particles. If there is an excess of coarse sand, however, over 20 per cent. or so, the soil loses water in dry weather both by evaporation and by drainage at too great a rate, and such soils under our conditions are scarcely suited to cultivation.

3. *Fine Sand.*—This is a decidedly characteristic constituent of cultivated soils in New Zealand, in which it usually occurs to the extent of 35 to even 50 per cent. It assists in binding the soil to some extent, while still allowing it to be friable, but it has little

capacity for retaining water, and unless the level of standing water is near the surface, soils containing an excess of fine sand soon "dry out" in the summer.

4 *Silt.*—Soils with 25 to 40 per cent. of this fraction are among the most valuable of cultivated soils, being sufficiently free-working and yet close enough in texture to prevent excessive loss of water by drainage. It will also be shown later that soils with much silt are best able to draw upon the subsoil for water when required.

5. *Fine Silt.*—Though the fine silt is not at all so plastic as clay, still it tends to increase the difficulty of cultivation when the percentage rises above 10 or 15. As a compensation, however, the water holding capacity of the soil is improved.

6. *Clay.*—This name covers all the finest particles of soil irrespective of their composition. Some of it consists simply of very finely disintegrated sand, while a portion of it is in colloidal form, that is, the particles, while being so small as to be invisible, are yet incapable of diffusing through a membrane, such as a bladder, after the manner of a dissolved substance. It is this portion which gives the stickiness or plasticity to ordinary brick clay, in virtue of which it is capable of being moulded into shapes after kneading with water. It is this part, too, which is permanently altered when clay is burnt; a brick, for instance, if powdered up and mixed with water will never return to a plastic mass. The same change is illustrated in the disintegration of the sod fences so common in Canterbury after a fire has burnt off the gorse growing on them. The natural plasticity of the clay in these sods preserves them until a fire destroys this property, after which they rapidly crumble away. When a little powdered clay is shaken up with some

water in a glass it does not settle down from suspension in the water for days, and even months. This property also is due to the colloidal part of the clay. But if a small quantity of an acid or of certain salts, such as bicarbonate of lime, is added to the clay water very soon the small particles are seen to run together and quickly sink, leaving the water quite clear. This phenomenon is called flocculation, but the change is not permanent, and the original condition is restored by washing away with water the flocculating agent. One of the main functions of lime on heavy lands is the flocculation of the clay fraction, whereby the soil is made more friable and granular, and hence drier and easier to work. The beneficial action of frost in improving the tilth of soils exposed to it during the winter is ascribed in part to its flocculating action. On the other hand alkalis, such as caustic soda, and their carbonates, have the opposite effect, a deflocculating action on the clay, increasing its plasticity and emphasising its normal characteristics. For this reason manures such as nitrate of soda,* which give up nitrate to the plant and leave soda in the soil in the form of carbonate of soda, affect the tilth adversely, and if their use is persisted in would ultimately make the soil unworkable. On the Rothamsted† plots, on which mangels have been grown continuously with such manures, the crop is sometimes completely lost owing to the bad mechanical condition of the soil induced in this way.

Clay is one of the most important constituents of the soil. In the proper amount it controls the water supply by preventing too rapid loss by drainage; if in excess it holds all the water too near the surface so that the roots are not encouraged to go down, and consequently become parched during a dry spell.

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*See page 106. †The famous agricultural experimental station founded in Herts, England, in 1843, by Sir J. B. Lawes (1814-1900), in conjunction with Dr. (afterwards Sir) J. H. Gilbert.

Excess of clay also makes the land sticky to work when at all wet, and causes it to dry into hard clods. Ten per cent. is a quite satisfactory amount, though in the drier districts a higher figure is not objectionable.

### Organic Matter and Humus.

All the materials dealt with so far are lifeless, inorganic, mineral substances. They alone, no matter how carefully the proportions might be adjusted, could not support the growth of ordinary plants, and soil comprises other things than these. When some soil is baked over a lamp or fire part of it is seen to burn away, and the residue is reddish in colour. The part that burns away is known as organic matter, because it is derived from living organisms, namely, from the decay of previous generations of plants that have lived and died in the soil. The stubble ploughed under in the autumn very soon decays and loses its ordinary characters; in fact, except for some fibrous and partially decayed pieces it has apparently disappeared. The changes which it undergoes are very complicated, but the final result is that the plant remains return whence they came, the carbonaceous part is oxidised and returns to the air or soil water as carbonic acid; the nitrogenous material is for the most part converted into nitrates, which are taken up by another generation of plants, or are washed into the subsoil; the mineral portion returns to the soil ready for the use of another plant. An intermediate product in this decomposition of organic matter is the material called humus, a term very often wrongly used, as though it were simply a synonym of organic matter. One cannot sift a soil between one's fingers and sort out the humus in that way. Humus is disseminated in a finely divided form; its presence is recognised, however, by the dark colour that it gives the soil, and this is why the soil in a vegetable garden, where waste leaves accumulate and rot, becomes so black. It is not a single definite compound but an indefinite mixture of varying composition, though its physical properties are fairly constant. In the laboratory it is most easily separated by shaking some good soil with dilute alkali, such as 2 per cent. ammonia solution, which dissolves it out, giving a dark-coloured solution from which the humus is precipitated as a brown flocculent material by adding dilute hydrochloric acid.

Apart from supplying plant food, humus especially, and the organic matter that produces humus, are of great importance in holding water and in maintaining the soil in a moist and free working condition, and no soil could be satisfactory without a moderate quantity of each, say 1 or 2 per cent., of soluble humus with 3 or 4 per cent of other organic matter as reserve. They have great cementing power, and by binding loose soils make them firmer and more friable. Like all other constituents, organic matter is needed in moderation; in excess it does harm, partly owing to the accumulation of acids derived from its further decomposition. Peat soils, for instance, being formed from the luxuriant vegetation encouraged by the stagnant water that once lay in the locality, have a great excess of organic matter, and are usually infertile, not merely from the lack of mineral food, but from the sourness caused by these acids.

## The Soil Water.

Every soil, even in the driest summer, retains some water distributed as films over the surface of its grains. It is obviously of the greatest importance as the medium through which every plant living in the soil receives its food, for it has dissolved in it the nutrients which feed both plants and micro-organisms. Owing to the impossibility of removing the true soil water completely from the soil we have no accurate information as to its composition. The chemists of the United States Bureau of Soils, after studying the solution obtained by stirring soil with water, affirm that the soil water is of nearly constant composition, and that the following constituents occur in the proportions indicated:—

phosphate, 7·64; nitrate, 5·47; lime, 11·67; potash, 22·74 parts per million of dry soil.

In consequence of this finding they have put forward some very startling views as to the function of fertilisers in the soil, but so far neither their premises nor their conclusions have been accepted by British agriculturists.

Analyses reveal that soil drainage waters contain only traces of ammonia and phosphate, and only very little potash; the chief constituents are carbonic acid, and sulphates, chlorides, and silicates of lime, iron, magnesium, and sodium. The total concentration of the Rothamsted drainage water varies from ·02 to ·05 per cent.

## The Soil Air.

The importance of air in the soil will be understood when it is recalled that the process of respiration goes on in every part of the plant, including the roots. About 30 per cent. of the volume of a dry soil is filled with air, but in a moist soil suited to plant growth 15 per cent. would be nearer the mark, and of course the figure is constantly changing according to the water content of the soil. Soil air differs little from the atmosphere above, except that it has a rather higher percentage of carbonic acid. Besides this free air in the soil interspaces there is an atmosphere of different character dissolved in the film water. It is almost devoid of oxygen, and consists mainly of carbon dioxide and nitrogen. The fact that it exists in such close proximity to the free air of the interspaces shows that oxygen is used up more rapidly than it is renewed, and this means that the plant roots and micro-organisms which are immersed in the film water are perpetually in need of more oxygen, which is supplied in part from solution from the free atmosphere, and in part from rain water. Rain in falling dissolves a considerable amount of oxygen, hence it is much more stimulating to plant growth than a similar quantity of water from the garden hose.

## The Soil Micro-Organisms.

The micro-organisms of the soil are important, both as regards their number and variety, and as regards their influence on the welfare of plants; in fact, the scope of this subject is too wide to allow of anything but the merest outline here. There is also among the micro-organisms of the soil a struggle for existence as keen as that which is waged among the animals and plants that inhabit the surface of the earth. Now it so happens that it is those bacteria that most assist plant growth, such as those that take part in the process of nitrification, that, generally speaking, suffer most in the struggle with larger, but useless, organisms such as amœbæ. It would appear, therefore, that if man could devise a method of so interfering in the competition as to assist the useful bacteria against their enemies, then enhanced fertility would be the result. Methods of interference, applicable on a small scale and frequently with beneficial results, have in recent years been studied very carefully by investigators at Rothamsted and elsewhere, among the more important of the methods being partial sterilisation by heating the soil to about 60°C., or by treating it with volatile antiseptics, such as toluene. It is believed that such treatment kills off practically the whole soil population, but does not destroy spores, and therefore organisms such as bacteria that reproduce by spores are not wiped out, but only temporarily checked, while larger types, such as amœbæ, which do not form spores, are killed off altogether. There follows presently, therefore, unusual bacterial activity owing to the absence of competition, and in cases where a lack of the products of useful bacteria has been a "limiting factor" to fertility, increased productivity follows.

It has been shown, also, that troubles such as the "sickness" that affects soils in green-houses that have been heavily manured and intensively cropped, are sometimes due to the dominance of harmful soil organisms, and may be cured by partial sterilisation. "Clover sickness" may be due to the same cause, while such troubles as "finger-and-toe" or "club-root,"* as well as many others, are known to be due to soil organisms. One may therefore, with reason, prophesy that the next great advance in the raising of soil fertility will have reference to the control of the micro-organisms of the soil.

### For Further Reference.

E. J. Russell—Soil Conditions and Plant Growth. 3rd Edn. Longmans, Green and Co.
A. D. Hall—The Soil. John Murray.
L. J. Wild—The Conservation of Soil Moisture. Canterbury A. and P. Association's Journal, 1917.
R. Warington—The Physical Properties of Soils. Oxford University Press.

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*See pages 38 and 88.

## CHAPTER II.

# PLANT NUTRIENTS IN THE SOIL.

We have mentioned that the soil is the home in which the plant lives and has its being, and also that it is the storehouse from which the plant draws its lime, magnesia, potash, phosphate, etc.—the raw material which it converts into plant substance. To those unfamiliar with chemical terms, it will be necessary to explain that these elements do not, and in the nature of things could not, exist free and separately in the soil, but they are combined with one another in a variety of groupings to form minerals such as silica, hornblende, mica, and so on, which constitute the grains of sand and silt already referred to. Let us consider a single example, the mineral mica, which forms the bright flakes in granite rocks, and the shiny grains in soils, such as those of the Taieri Plain, derived from the mica-bearing schists of Otago. It contains the elements hydrogen, oxygen, potassium, aluminium, and silicon combined together as a silicate of potash and alumina. As a result of decomposition and solution, the soil water surrounding grains of mica will probably have in it minute quantities of potassium carbonate, containing potassium, carbon, and oxygen (the carbon dioxide being derived from the soil air); and aluminium silicate containing aluminium, silicon, hydrogen, and oxygen. The solutions containing these compounds diffuse into the plant, and the elements are then built up again on different plans to form the plant substances already mentioned. The matter is advanced another stage when the animal feeds upon the plant, digesting some of the constituents and remodelling them into still other compounds suitable for taking a place in the tissues of the animal body, while other constituents remain undigested and are excreted. In all these cases we are dealing only with compounds built up from the same elements differently arranged, just as the same timber, iron, and nails may be built up to form a stable or a mansion.

We shall now discuss the effects on plant growth and development of an excess or deficiency in the soil solution of the more important essential constituents.

*Water.*—The natural vegetation of situations such as swamps having an excessive water supply is characterised by large broad leaves and succulent stems, while that of arid areas has bristly foliage and wiry stems. With agricultural crops the effect of an abundant supply of moisture is to prolong the period of growth and delay the ripening of seed or grain. In North Canterbury, where the annual rainfall averages 26in., harvesting normally begins in January, while in Southland, where the rainfall is 46ins., operations do not begin till March, and the delay is due mainly to the moister summer conditions. On the other hand, lack of moisture causes premature seed production, the plant apparently making a special effort to leave seed so soon as unusually dry conditions warn it of its approaching end. The Canterbury drought of 1915-16 affords an instance, many crops of oats having run to ear in October.

*Nitrogen Compounds.*—Nitrogen is absorbed either as ammonium salts or as nitrates; most plants evidently prefer the latter, a few prefer the former, while still others are quite indifferent. Leguminous crops, such as clovers, peas, beans, vetches, and lucerne, draw to a considerable extent upon the atmosphere for their nitrogen.* When the supply of nitrogen in a soil is largely in excess of plant requirements the result is a luxuriant growth of dark green foliage. Such plants show little inclination to produce seed; they are soft, succulent, and attractive to insects and fungoid pests, and in the case of cereals produce much weak straw, which is unable to support its weight, and is beaten down by wind and rain. This is frequently noticed in places where stack bottom has been ploughed under, and often in moist warm seasons with lea oats or wheat, owing to the supply of nitrogen from the rapidly decaying vegetation. With crops that are grown for seed, fruit, or tubers. and which, on account of climatic conditions must be harvested at a fixed season. excess of nitrogen is unprofitable, for the increased leaf and stem is not accompanied by an increased yield of the desired product. But in the case of carrots, turnips, and mangels, which remain in the ground till late autumn or winter, the increased root is in the end obtained. Also to crops such as rape and silver beet, grown wholly for leaf and stem, excess of nitrogen is generally advantageous.

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*See page 43.

Lack of nitrogen is generally manifested in yellow leaves, lack of growth, and a stunted appearance.

*Phosphates.*—The most striking result of a full supply of phosphates is a stimulation of root development, as was pointed out by Lawes* as long ago as 1847. In New Zealand we have evidence of the same thing in the universal use of phosphatic manures, even in soils that, so far as we can tell, are not deficient in phosphatic material of a readily soluble nature. The improved crop is no doubt largely due to the vigorous root development encouraged by the dressing of phosphate applied in the neighbourhood of the seedling. The response of wheat to phosphates in Australian soils has a similar explanation.

As the plant approaches maturity a sufficiency of phosphate is said to hasten the ripening process, but under our conditions any effect in this direction is likely to be obscured by that due to variations in the supply of moisture.

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*See footnote page 13.

The effect of phosphates on the nutritive value of pastures is an aspect of this question to which too little attention is paid. An extreme case, probably due to lack of phosphates, and at all events prevented to a large extent by phosphatic manuring, is the "bush sickness" that afflicts stock in some parts of the pumice areas of the North Island. But the "depraved taste"* (that is the habit of chewing bones, etc.,) frequently exhibited by cows is undoubtedly a sign of the deficiency of the herbage in some nutrient such as lime or phosphate. In general, the best pastures for fat lamb raising as well as for milk production are those on soils containing a liberal supply of phosphates.

*Potash.*—The symptoms usually accepted in British practice as indicating a deficiency of potash are dull-coloured leaves dying at the tips, loss of vigour and condition, susceptibility to insect and fungus attacks, and a loss of efficiency in carbohydrate production, which in the case of roots is seen in reduced yield. and with cereals in small and pinched, though not less numerous, grains. These signs, however, in the case of New Zealand soils are capable of a different interpretation, being more frequently due to lack of water or of phosphates.

*Lime.*—An abundance of lime is said to stimulate root production and to give increased tone to the plant. In Southland its use has a remarkable effect on the feeding quality of pastures, though doubtless this is due to a change in the botanical composition of the pasture, more especially to an increased percentage of clovers, rather than to a change in the chemical composition of the plants. However, as lime acts on the soil as a whole as well as on its individual constituents, and on account of the importance of its physical and biological effects, a complete discussion is given in a separate chapter. (See page 86).

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*See page 89.

*Magnesia.*—This constituent is not required in great amount, and soils having a deficiency of it are extremely rare. An excess, however, relative to the lime content is harmful, and authorities are not wanting who consider that there should be a definite ratio of lime to magnesia, about 1 to 1, though the ratio varies with different kinds of plants. Mr. Aston* suggests that on account of a disproportionate amount of magnesia to lime, soils in the following localities would probably respond to liming:—Manawatu and Wairarapa; Pakihis of Westland; Marlborough; Ohau Bay and Whangaroa; Catlins; also soils derived from mica schist rocks, and many Canterbury soils.

*Iron.*—Most soils contain a sufficiency of iron compounds which the plant demands for chlorophyll formation, though iron is not a constituent of chlorophyll. In the North Island dressings of iron sulphate act as a preventive of "bush sickness" in areas susceptible to this trouble, but otherwise iron salts are not required as manures.

*Sulphur.*—This is wanted in only small quantities as plant food, and is present in sufficient amounts in all soils. The benefits described from its use at Ruakura Experimental Farm and elsewhere are probably due to its checking the growth of injurious microscopic plants.

Of the constituents mentioned above, normal soils usually have magnesia, iron, calcium, and sulphur in greatest excess relative to the requirements of plants. The quantities of the remaining three, therefore, namely nitrogen, potash, and phosphates, tend to become limiting factors of plant growth, for, as the German chemist Liebig (1803-1873) states in what is known as the Law of the Minimum, "the limits of fertility are fixed by the amount of the particular constituent of plant food which is most deficient in the soil."

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*B C. Aston, Chemist to N.Z. Dept. of Agric.

## CHAPTER III.

# SOIL FERTILITY AND THE PRINCIPLES OF MANURING.

### Natural Fertility.

The natural productiveness of a soil depends not only on those properties inherent in the soil itself, for example its chemical composition and physical texture, but also on the external conditions to which it is exposed, such as its position with reference to standing water, the annual rainfall, temperature, amount of sunshine experienced in the locality, and so on. An animal, for example a human being, requires for healthy development not only a sufficient supply of suitable food, but also a congenial environment. So also with the plant: not only is food essential, but the conditions as regards air and moisture supply, temperature, and the presence or absence of harmful factors must be suitable. In some soils all this is naturally the case, and production is easily maintained; manures are used chiefly to keep up fertility, and are selected accordingly, having in mind the constituents on which the system of farming practised exercises the most severe strain.

Where unproductiveness is due primarily to unhealthy soil conditions this matter must first be set right. For instance, if the soil is waterlogged for a great part of the year, draining to remove the excess must be attended to. After that, liming to remove sourness may be necessary. Or, again, it may be that the texture of the soil is bad on account of a lack of organic matter, or perhaps because of excessive stickiness, which goes with a high percentage of clay; and such defects must be removed as a preliminary to improving the supply of plant food. Above all things thorough cultivation is of fundamental importance as a means of bringing the soil into productive condition. Cultivation will go far towards removing the necessity for manuring, a principle insisted on by Jethro Tull two centuries ago; but no amount of manuring will compensate for indifferent cultivation.

## Limiting Factors.

For any given soil there is usually one factor which more than any other is the cause of diminished productivity. Such a factor is called a limiting factor, and it is the business of the farmer to find the limiting factor in the case of the soil with which he is concerned. It is a principle of the utmost importance, though one that, unfortunately, is frequently overlooked, that until this factor is put out of action any soil treatment not tending in that direction will not increase production. Thus, if a soil is waterlogged for a considerable part of the season the application of fertiliser will be useless until the land is drained. Or, if phosphates are deficient in the soil, the application of nitrates will be ineffective except in so far as the crop is thereby stimulated to a more active search for phosphates, as indeed it may be to a slight extent.

Let us consider briefly some of the factors that commonly limit productivity either as regards the kind or the amount of crop produced.

1. *Water Supply.*—The importance of a well-regulated supply of moisture in soils cannot be overemphasised. Under natural conditions water supply determines the character of the plant covering almost as much as does the quality of the soil. Thus the rainfall of the West Coast has enabled the land on

that side to clothe itself with a magnificent forest growth, while the richer soils of the eastern plains, with their scanty rainfall, were able to produce only a covering of coarse grasses and tussocks. Equally as important as rainfall are situation and slope of the land; facilities for surface run-off or for under-drainage; and the mechanical composition of soil and subsoil which regulates both the upward and downward movement of water. Swamps in low-lying places and loose sand hills and dunes have each their peculiar vegetation. The porous pumice plains* of the North Island bear a scanty growth of manuka and bracken, but where water-courses supply the same soil with enough moisture a rich vegetation results.

Besides total rainfall its distribution throughout the year is also important. At Lincoln, May, June, and July are the wettest three months. August is a comparatively dry month, but because of the previous rains the soil is always wet. On the other hand, though March is, except for July, the wettest month in the year the soil then is never really wet because of the preceding dry weather.

Over rainfall, situation, and slope the farmer has little or no control, but where the fault lies in the soil, or even in the subsoil, much can be done. Where an impervious subsoil prevents the escape of excess of water it must be broken by explosives or by sub-soiling implements. If the slope is insufficient to provide a run-off naturally it may still be quite sufficient to carry off the water in open, tile, or mole drains. If the soil itself is too retentive because of excess of clay or of organic matter much may be done by liming and draining. If soil and subsoil are too porous recourse may be made to the subsoil-packer and roller, to green-manuring, and to heavy stocking during the feeding off of fodder and root crops.

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* See page 51.

The conservation of the water supply is a matter of storing as much as possible by having the soil in an absorptive condition during the period of rains, and keeping it there by having the surface soil always loose, so that the continuity of the upward flow from the subsoil is broken below the surface whereby evaporation therefrom is minimised.

Finally, where the probable results warrant it, irrigation may be arranged for, but this is ultimately mainly a problem in engineering.

2. *Air Supply.*—Remembering that both plant roots and soil bacteria require oxygen, the necessity for complete æration is obvious. Thorough cultivation, combined with whatever steps are necessary for the riddance of excess of water, is the chief means of ensuring this. Water and air are mutually exclusive; draining, subsoiling, and so on, that set up a circulation of water, also cause a circulation of air.

3. *Temperature.*—For all agricultural crops there is a temperature below which growth is so slow as to be negligible. Rapid and prolonged growth of, say, grass, depends in part upon warmth in early spring and in late autumn. If the sun's rays have to evaporate excess of soil moisture then so much the less are they able to warm the soil itself. Good drainage, therefore, is essential to a warm soil, and any tendency to waterlogging is a preventive. In Southland, for example, the naturally under-drained soils of the Dipton and Bayswater Flats will grow wheat quite successfully, but over the cold heavy clay subsoils of the plains the wheat is usually frosted.

The farmer has little control over soil temperature except by such methods as may be employed to get rid of excess of water. For some crops he may ridge the land, thus exposing more surface to evaporation and one of them more directly to the sun's rays.

Dressings of dark-coloured, heat-absorbing materials, such as soot, are useful, but usually impracticable, though the increase of humus brought about by green-manuring helps.

4. *Presence of Harmful Conditions.*—It sometimes happens that soils are infertile despite a good supply of moisture, air, food, and so on, the cause being the presence of some injurious substance. Thus the soils of the Dun Mountain area, in Nelson, are barren because of an excess of magnesia; wet soils poor in lime also seem to possess some substance or substances inimical to the growth of ordinary crops.

It is well known that persistent cropping with one variety of crop without manure results in a serious diminution of yield. Long ago De Candolle* advanced the hypothesis that plants, like animals, excrete substances harmful or toxic to themselves and to other crops of a like kind. The workers of the American Bureau of Soils have recently revived this theory, and to the presence of toxins they ascribe infertility almost whenever met with. To traverse their arguments fully would take up too much space, but their main points are as follows:—(1) Plants feed in the films of moisture coating the soil particles. (2) This soil water has approximately the same composition in all soils, rich and poor. (3) Such differences in composition as do occur have, so they claim to have shown, no effect on plant growth. (4) There must, therefore, be in poor soils some harmful substances not present in rich soils. (5) These toxins are some of them produced by the normal decomposition of soil organic matter, but others are excreted by plants. (6) The function of manures and fertilisers is primarily to put out of action these toxins; they cannot serve merely as plant food, because (they say) they do not alter the composition of the soil solution.

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*A famous Swiss botanist (1778-1841) professor of botany at Montpellier University and later at Geneva.

(7) Rotation of crops helps to maintain fertility because the toxins excreted by one kind of plant are not harmful to unrelated types of crops.

British workers entirely reject the "toxin theory." With the eminently suitable material provided by the soils of the unmanured plots at Rothamsted that have carried one crop continuously for over 70 years, Hall* could find in them no evidence of toxins. Both the soils themselves and their aqueous extracts produce crops of wheat, barley, or oats without discrimination; moreover, the soils that have received manures lacking only phosphates respond to phosphates but not to potash, while with those that have received a manure lacking only potash the reverse is the case.

Notwithstanding the negative evidence of the workers at Rothamsted, there is now quite satisfactory proof that at least some plants do produce excretions that have a depressing effect on some others under certain conditions. The Woburn† experiments on the effect of grass growing round fruit trees provide such proof, and many American experiments are also conclusive. But whether these excretions are capable of producing the effects claimed for them on ordinary farm crops grown under ordinary conditions is extremely doubtful, because they are substances of unstable chemical composition likely to be destroyed by the æration resulting from thorough cultivation, and especially from such treatment as liming.

It has been suggested that the harmful effect of weeds on ordinary crops is due to the toxins they excrete. The damage may, however, be due to the competition between two root systems for the available root space and for the moisture, air, and plant food.

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*Sir A. D. Hall, British Development Commissioner, at one time Director of Rothamsted.

† An English experimental farm established by the Duke of Bedford.

5. *Supply of the Elements of Nutrition.*—If the general soil conditions as regards moisture, climate, tilth, etc., are favourable, productiveness then depends mainly on the supply of available plant food. Every New Zealand soil contains some at least of each of the essential elements* of plant nutrition. It is quite wrong to suppose, as is sometimes popularly considered, that the infertility of this or that soil is due to the absence from it of one of these elements; and even if it is admitted that fertility or infertility is due to an excess or deficiency of one or other of these elements we are still unable to state in numerical terms what constitutes an excess or deficiency. Every soil, therefore, under ordinary conditions, gives at least some yield of crop, though not necessarily a profitable return. As has already been stated (page 23), the amount of crop depends on the quantity of that constituent in which the soil is relatively most deficient. Now the constituents demanded by plants in relatively greatest quantity and contained by soils in comparatively least amounts are three in number. namely, phosphates, nitrates, and potash, the principal elements in which are respectively phosphorus, nitrogen, and potassium. When an ordinary soil is cropped continuously without manures and the crops are removed the yield diminishes for some time, but finally reaches a level below which the average does not sink. Thus on the famous Broadbalk field at Rothamsted, on which wheat has been grown continuously since 1843, the yield has been practically constant at 12½ bushels for the last fifty years. This apparently implies that only enough of that constituent which is available in

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*These are nitrogen, phosphorus, sulphur, potassium, magnesium, calcium, iron, (in small amount), and probably chlorine. It is very necessary to understand that these elements occur in the soil not as single elements but combined together with others, forming a variety of compounds of varying degrees of solubility.

least amount is set free during each year by the natural processes of decomposition and solution to enable a yield of 12½ bushels to be produced. In this case the element in greatest deficiency is nitrogen; it constitutes a limiting factor, for while the plot manured each year with phosphates and potash has yielded an average of only 14½ bushels, that manured with nitrogen compounds alone has yielded 20 bushels. Most of our soils, however, show a deficiency in phosphates under average conditions; or, in other words, if the general condition of the soil is healthy the phosphate supply is the limiting factor.

## Soil Improvers and Fertilisers.

We see, therefore, that the productiveness of a soil depends on its possessing in as high degree as possible a wide variety of factors. Substances added to the soil for the purpose of securing any one or more of these factors are usually known as manures or fertilisers. In this book it is proposed to classify all such substances under two heads—A., Soil Improvers; B., Fertilisers. By a soil improver is meant a substance employed to make the soil a better habitation for the plant, whether by altering the bacterial population, or by improving the moisture supply and æration, or by adding plant food, or by altering the condition of that already in it. Examples of this class are farmyard manure, lime, and green manures. By a fertiliser is to be understood any substance or mixture of substances applied solely for the sake of the constituents of plant food contained therein, good examples being superphosphate, sulphate of potash, nitrate of soda. Of course it is not pretended that these definitions are mutually exclusive. Fertilisers are sub-divided into classes according to the constituent which each provides; thus we have nitrogenous fertilisers, phosphatic fertilisers, and potash fertilisers. Those, such as bone dust and guano, which provide more than one of the essential elements, are classed as compound fertilisers.

## Theories of Manuring.

Soil improvers are usually employed with a view to future crop production rather than with an idea to the immediately succeeding crop, though application is usually made before that crop in the rotation which is likely to receive most direct benefit. The immediate purpose of a fertiliser is to bring about an increase in the crop to which it is applied. It is, therefore, approximately true to say that soil improvers are intended to feed the soil, while fertilisers feed the crop. The Rothamsted experiments already mentioned have proved that the inherent fertility of a soil is great enough to permit of the continuous removal of crops for long periods without return to the soil in any shape or form. Nevertheless, economic farming usually demands at least a partial restoration of what has been taken in order that production may be maintained at a payable level. In sparsely populated areas, where land is cheap and fairly good, it may be most economical to rely on the natural fertility of the soil, moving on when signs of exhaustion appear. But where land is scarce and dear it will probably pay to raise the fertility level by liberal treatment. The price of produce is doubtless the determining factor. When prices are low the increase in yield may not refund the outlay in manure; hence Lawes's maxim: "High farming is no remedy for low prices."

One of the earliest theories of manuring was the so-called Ash Theory, propounded by Liebig as a result of the data afforded by the analyses of plant ashes. His idea was simply to use as manure substances containing the elements found in the ash of the crop, on the assumption that this material alone was derived from the soil.* In the first place, this theory exaggerates the plant's requirements, because it does not allow for the unessential elements such as sodium and silicon. Again, even as regards the essential constituents, it does not take into consideration how small are the requirements of one crop in comparison with the reserves in the soil.

Even in the case of the three elements of which plants are apt to experience a shortage, it is by no means true that that found in greatest amount in the ash is the one that is most essential in the fertiliser. Thus, an average crop of swedes removes 150lbs. nitrogen per acre, 30lbs. phosphoric anhydride, and 120lbs. potash; yet a phosphatic fertiliser alone is required. This and other facts of a similar kind led the French authority, Ville, to formulate what is known as his Theory of Dominants, which states that for each crop there is a "dominant" fertilising constituent, frequently the one of which the plant ash contains least. This theory, however, applies with only a few crops, and even in these cases the facts are capable of other explanations.

The fact is that our understanding of soil conditions and crop requirements is still too slight to admit of the formulation of rules. Each type of soil still demands experimental investigation, a method which is slow but tolerably sure of yielding reliable conclusions.

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* Incidentally it may be mentioned that this theory was based on a misconception of the facts, the element nitrogen, though not present in plant ash, being derived mainly from the soil.

## Rotation of Crops.

It has already been stated that different cro remove different proportions of the three importa constituents from the soil. It is suggested, therefor that by taking various crops turn about the drain o the fertility is equalised. Modern ideas concernin the nature of the soil solution seem, however, to di credit this explanation of the benefits derived fro rotation of crops. It is more probable that the benefi are due to the opportunities that a rotation of cro affords of ridding the land of weeds, and of fungoi and bacterial pests, and of cultivating the soil i different seasons and to different depths. Moreover rotation of crops does not prevent the necessity having ultimately to restore to the soil, either directl or indirectly, something of what has been remove The Rothamsted experiments afford ample proof this. On the unmanured plots that have been croppe in a rotation of swedes, barley, clover, wheat sinc 1848 the average production from 1884 to 1911 wa 15 cwt. swedes, 14½ bushels barley, 10 cwt. clover ha and 25 bushels wheat. The yield of wheat, and to lesser degree that of barley, has indeed been tolerabl well maintained, but this is due in no small degre to the fact that the yields of swedes and of clove have been so poor that practically speaking the lan has been fallow during its occupation by these tw crops. On the plots treated with a complete manur the average yields during the same period were 37 cwt. swedes, 28 bushels barley, 40 cwt. clover hay, an 35½ bushels wheat.

## The Specific Effects of some Fertilisers.

Years ago Lawes noticed the greatly increase growth of rootlets and root-hairs produced by the us of superphosphate. This effect probably partl accounts for the good results obtained from the use of superphosphate on wheat in the dry districts of Australia. Nearly every New Zealand farmer knows the effect that a small quantity of phosphatic fertiliser sown with the seed has on the turnip crop. The same quantity broadcasted would be quite ineffective. Each soil particle near the seed and fertiliser apparently sets up round itself a film of concentrated solution in which the young rootlets get a strong start.

Basic slag contains two useful constituents, namely, lime and phosphate. But its characteristic effect on grass land is more striking than that resulting from the use of lime and any other phosphate. The slag has some specific action, though one that is not yet understood.

### Recapitulation.

Summing up, we find that the fertility of a soil is governed by one or more limiting factors, which may be inherent in the soil or may be seasonal. Thus the main limiting factor in the case of the soils of Hawke's Bay in the 1913-14 season was moisture, and this was the case in Canterbury in the season of 1915-16. Where the limiting factor is air, warmth, the presence of toxic substances, or difficulty of root movement, cultivation, subsoiling, draining, and liming will be found to effect an improvement. Finally, when the limiting factor is a deficiency of plant food, direct or indirect manuring is the remedy. In most of our soils phosphoric anhydride is the main deficiency, so that phosphates make up by far the greatest portion of the manures imported into our country.

#### For Further Reference.

E. J. Russell—The Fertility of the Soil. Cambridge University Press.
F. H. Cameron—The Soil Solution. Chemical Publishing Co.
Hall, Brenchley, and Underwood—The Soil Solution and the Mineral Constituents of the Soil. Journal of Agricultural Science, Vol. VI., p. 278.

## Chapter IV.

# THE IMPROVEMENT OF FERTILITY.

### Fallowing.

If instead of a crop every year one is taken onl every other year, the land between times lying fallow then both higher yields are obtained because of th longer period for the accumulation of available plan food, and the fertility level falls very much mor slowly. Thus the Rothamsted wheat without manur alternating with fallow has yielded an average o over 16 bushels per acre over a period of 58 year This system of fallowing every second or third yea is specially useful where moisture is the factor tha limits production. In the "Great Plains" region o Canada, a famous wheat-growing area, where th rainfall is 12 to 15 inches per annum, the usua custom is to take a bare fallow one season in three i order to accumulate the moisture for the benefit o the two following crops.

### Rotation of Crops.

Continuous growing of one crop or of one type o crop, especially of a kind that is wholly removed fro the field, such as wheat, oats, and barley, is especiall severe on a soil. This is due only in small measure t the disproportionate removal of the various elemen of fertility. It is sometimes said that continuou cropping with wheat reduces the yield because whea removes more of nitrogen than of potash or of pho phoric anhydride, and in consequence the lack of nitrogen becomes a "limiting factor"; in the same way it is said that lack of potash becomes a "limiting factor" to production when attempts are made at continuous cropping with swedes, which remove more of potash than of the other two elements. The rest of the argument may be shown as follows:—

| | Nitrogen | Phosphoric Anhydride | Potash |
|---|---|---|---|
| | lbs. per ac. | lbs. per ac. | lbs. per ac. |
| 2 Crops of Wheat remove | 100 | 42 | 58 |
| 2 Crops of Turnips (root) remove | 200 | 46 | 180 |
| 1 Crop of Wheat and 1 Crop of Turnips remove ... | 150 | 44 | 119 |

The inference is that changing the crops "equalises the drain of fertility" and spreads it more uniformly over the various constituents. Unfortunately, however, soil fertility is not a problem capable of an arithmetical solution. and this argument fails to take account of modern ideas regarding the nature and composition of the nutrient solution of the soil.

Arguments in favour of rotation of crops are not, however, totally unrelated to soil composition. If we consider a common New Zealand rotation of turnips, oats, and three years grass, we find that under our conditions, in which roots are fed off and grass is grazed, only one crop, namely oats, is entirely removed from the field. Of the soil-derived elements contained in the turnips and grass at least 70 per cent. is returned as animal droppings to the soil, which is further enriched by the humus-forming organic matter.

But there are many other benefits accruing fron rotations, some of which will now be mentioned. On of the most important is the opportunity afforded o suppressing weeds. There are some crops—wheat i a good example—that occupy the ground so long a not to give opportunity for the eradication of weeds which grow with the crop, shed their seed, and th seed for the next wheat crop must be sown before th weeds have had time to germinate and to be harrowe out. By alternating such a crop with one like mangel or potatoes that requires inter-cultivation, or with on like peas or turnips, that is sown late in spring, givin time beforehand for the grubbing out of weeds, th ground is kept much cleaner, to the advantage of bot crops. The main difficulty with the Rothamsted plot on which wheat has been grown continuously for ove 70 years is that weeds have now obtained such a fir hold as to require hand pulling in order to get a cro of wheat at all. A paddock bought into the Lincol College farm many years ago was in almost complet possession of sorrel simply because it had carrie wheat for each of the previous 13 years.

Besides weeds of the ordinary kind there are othe pests that succumb to a rotational system of croppin Potatoes take "blight," swedes suffer from "clu root," land becomes "clover-sick," and so on. No all the specific organisms to which these troubles a due are got rid of by planting the land affected wi some crop other than that which supports t organism. In other words rotation of crops is the ke to the riddance of disease.

The preliminary cultivation and preparation nece sary for different crops varies considerably. Whe prefers a firm substratum of soil, while fairly lar lumps on the surface are no objection, since these a broken down by the winter frosts. Mangels favo a deeply-tilled soil and a fine seed-bed. Moreover, the rooting systems of various crops differ greatly, some rooting deeply and searching the soil thoroughly, while others, such as barley, are more shallow-rooted. A rotation of crops, therefore, ensures that a good tilth will be maintained by the different methods of cultivation at different times of the year according to the requirements of the different crops; and further that the soil will be uniformly exploited for plant food. On the whole, however, the advantages of rotation of crops relate to the biology and physics rather than to the chemistry of the soil.

Nothing that has been said in this section, can, however, get over the fact that in the long run fertility must fall, no matter how careful a rotation is practised.*

## Compensation for Fertility Removed.

It is a truism that there is a limit to everything. The constituents of a soil are like a deposit in a bank upon which drafts are made periodically; but as this procedure cannot go on indefinitely without inward payments to compensate the withdrawals, so neither can a farmer go on reaping crops and growing sheep, selling grain, wool, and mutton off the farm without its fertility falling away, unless he restores the elements of fertility either directly in the form of suitable manures or indirectly as soil improvers, or by other devices. These methods of compensation we shall now consider.

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* See page 34.

## Deep Ploughing; Subsoiling; The Use of Deep-rooting Plants.

In new countries where land is cheap the farme adopts that system of farming that involves the leas expenditure. As soon as he has exhausted one farm by this system he moves on to new land, and repeat the process. Where the supply of virgin land i limited as regards acreage this procedure is impossible But if the farmer cannot find new soil by goin further afield in one direction he may often find i nearer at hand by going in another direction, namely downwards. Careful exploration and preliminar trials are, however, necessary, because deep-ploughin is risky, and positively harmful in cases where puggy clay subsoil lies near at hand. In such circumstances subsoiling should first be practised, whereb air is admitted and the oxidation of the clay compounds is hastened. The growth of deep-roote pasture plants is also an excellent preliminary, fo the decay of roots in the subsoil leaves air-admittin openings, while the organic matter encourages th migration of earthworms to those regions. Moreove deep-rooting plants during their growth transpor food materials from the subsoil to their leaves an stems which, decaying, leave this matter in th surface soil.

## Cultivation.

To those who have followed the teaching of th book up to the present point the many ways in whic cultivation bears upon fertility should be eviden Over 200 years ago when Jethro Tull laid dow the important principle, already mentioned,* th "cultivation is half manuring," the close connectio between cultivation and fertility was only part understood. Cultivation provides the firm yielding seed-bed in which the young plant secures a safe anchorage. It loosens the soil so that roots can range freely in it in search of food and water. It assists in getting and maintaining that delicate adjustment of the supplies of air and moisture so essential to healthy plant development, not only in so far as air and moisture are required by crops, but also in so far as they are necessary to the disintegration and decomposition of soil particles, whereby plant food is made available, and also to the activity of the soil micro-organisms on which the supply of nitrogen to a large extent depends. The literal meaning of "to manure" is "to work by hand," showing that in earlier days of agriculture thorough cultivation of the soil was relied on to provide the supplies of plant food that in modern times we supply more quickly, and perhaps more abundantly, but scarcely more rationally, from the fertiliser bag.

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* See page 25.

## Indirect Manuring.

Thus far, we have discussed methods of forcing the soil to yield more abundantly and more willingly of its natural fertility. But we have already indicated that the process of taking all and returning nothing cannot go on indefinitely, and we are now forced to a consideration of the methods of paying back to the soil something of what we remove. We have already shown that the three constituents on which the drain falls most heavily are nitrogen, potash, and phosphates. The obvious method of returning these is to apply nitrogen salts, such as nitrate of soda and sulphate of ammonia; potash salts, such as kainit and sulphate of potash; and phosphatic manures, such as superphosphate, basic slag, and Island guanos. But bearing in mind the all-important necessity of farming economically, we shall readily be excused for one further endeavour to escape the use of these exceedingly high-priced fertilisers by finding if possible some method of farming or of manuring that will enable us to replace them indirectly. It will be convenient to consider the case of each constituent separately.

1. *Nitrogen.*—New Zealand soils are as a rule richer in nitrogen than are those of England; the average content of the soils of the chief arable districts in New Zealand is ·25 per cent., as compared with ·15 per cent., which is the average of some typical fertile soils of England. On the whole, too, our climate is milder than that of Great Britain, so that we should expect the conversion of the nitrogenous matter of the soil into nitrates to proceed at a more rapid rate and for a greater annual period than is the case at Home. At all events the supply of soluble nitrogen compounds in our soils rarely seems to be deficient, for experience shows that the artificial application of them gives little result except in the case of roots, which respond to a dressing of nitrate of soda or sulphate of ammonia, and for leafy crops such as rape and kale, which are grateful for a blood or other animal mixture. One can find very few experimental results bearing on this point, but all the evidence of good farm practice throughout the country supports the statement made. Perhaps the best test case is wheat. At Home, nitrate of soda is almost universally used as a top-dressing for this cereal in spring, just when the supply of nitrates is at its lowest ebb owing to the inactivity of bacteria during the winter. In New Zealand this practice is as universally not followed, and the inference is that the supply of nitrates in our soils never falls so low, this no doubt being due to a combination of circumstances—the greater reserve of organic matter, the

less severe winters, and the more rapid rise of soil temperature in the spring.

It appears, therefore, that our concern is not so much to add soluble nitrogenous salts which can be had only in the form of expensive artificial fertilisers, as to maintain the reserves of organic matter in the soil, and, for the rest, to trust to the soil micro-organisms. This is most cheaply done by ploughing in all refuse such as leaves, etc.; by feeding off crops, straw, etc., on the land; by scattering and ploughing in stack bottoms and the residue of stacks of straw that have been consumed in the fields; by running the chain harrows over grass land so as to scatter the animal manure; by getting and maintaining a thick turf of grass that will furnish bulky organic matter when the field is ploughed. A glance at the table on page 66 will show the fertilising constituents removed from a field by the **leaves only** of an ordinary crop of mangels. Few farmers would cart these off with the roots—an unnecessary procedure—if they realised that they are equivalent to a dressing of 4 to 5 cwt. of blood, 1½ cwt. of sulphate of potash, and 1 cwt. of superphosphate of lime. To burn a stack of wheat straw is to waste the fertilising elements it contains; to have it consumed by cattle and to spread the residue and the droppings is to return more than half to the soil, for the animal builds into its body only a small proportion of these constituents. However, even by these methods we are merely preventing waste; we are only **returning** to the soil some of that which we had **previously removed** from it, and therefore the net result is still a loss. But in the growth and feeding off or turning in of **leguminous** crops,* we are actually adding to the soil nitrogen which was not previously in it, for legumes, as has already been mentioned, draw largely upon the atmosphere for their nitrogen.

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* See page 20.

The key to the maintenance of the supply of nitrates in our soils is, therefore, not the use of expensive artificial manures, but the upkeep of the reserve of organic matter by feeding off and ploughing in crops and crop residues, and especially pod-bearing ones; and further, the thorough cultivation and æration of the soil, with the addition of lime where necessary, so as to encourage the activity of the nitrifying bacteria.

2. *Potash.*—In Great Britain it is said that thin chalky soils, sandy soils, and soils rich in organic matter respond to potash manures; and further, that carbohydrate-making crops, such as mangels and potatoes, require more potash than the soil provides. It is also recognised that soils with much clay have a correspondingly large reserve of potash. In New Zealand we lack the teaching of any systematic local experimentation; but the general consensus of opinion is in favour of potash manures for potatoes, though observation shows that salt may take its place with the mangel crop,—as indeed might be expected, since sodium is capable of replacing potash in the insoluble soil compounds. As regards soils, the areas of thin chalky and of sandy soils in ordinary cultivation are relatively small, while by far the great majority of our occupied soils contain at least moderate amounts of clay. The available analyses also indicate considerable reserves of potash. It is, therefore, not surprising that there is no definite evidence of increased fertility due to the use of potash manures. Experimental results so far published are of little value considered individually, but by taking the average of them all we get what is no doubt a useful

generalisation. Following are some average results:—

| Crop | No. of Experiments | Yield per Acre | | |
|---|---|---|---|---|
| | | Untreated | Phosphates without Potash | Phosphates with Potash |
| Mangels | 14 | 26·3 tons | 45·2 tons | 45·2 tons |
| Cereals | 11 | 54·2 bush. | 63·9 bush. | 58·7 bush. |
| Turnips and Swedes | 53 | 13·7 tons | 25·8 tons | 25·3 tons |

These figures must be taken with due caution; they do not say that on this or that soil potash manures will not pay; they do tell us that on average soils under average conditions potash salts are not likely to give an increased yield.

But we have still to answer the question: How are we to make good the supplies of potash sold off the farm? Must we apply potash salts to keep the account square, notwithstanding the fact that there is no visible result? No; for here is a case where all the evidence points to our being able to draw upon the reserve for a considerable time without straining our credit. In the first place the reserve is extremely large, as is shown from analyses; then, again, the actual removal of potash from the farm is not great; in the case of cereals most of the potash removed remains in the straw, which is usually consumed on the farm, whereby nearly all is returned as manure, for the animal really absorbs very little potash. Roots draw heavily upon the potash supply in the soil, but roots are nearly always fed off, so that there is little loss, the potash merely moving in a cycle from the soil, to the roots, to the animal, and back to the soil.

Considering these facts, the most careful farmer need have no scruples about neglecting to employ the high-priced potash manures from the German mines, unless he has definite experimental evidence of their value on his own farm, and excepting always, say, 1 cwt. per acre for the potato crop. But instead of returning potash he will do well to apply sodium or lime compounds, which the soil is willing to receive *in exchange* for potash. Potassium in the soil is for the most part "locked up" in somewhat insoluble compounds, but in the presence of sodium and lime and certain other elements some of the potassium comes into a soluble condition, while the sodium or lime joins the insoluble compound. At Rothamsted, crops manured with magnesium or sodium salts have been found to take up much more potash than plants not so treated. The farmer in this country, by using sodium chloride (common salt) for his mangels, and by an occasional application of burnt lime, or carbonate of lime, or gypsum, together with the thorough and deep cultivation already urged, can avoid for an almost unlimited period the necessity for the use of potash manures.

3. *Phosphates.*—The outstanding feature of New Zealand soils is their demand for phosphatic manures, which give increased yields with almost all crops on almost all soils. In the case of swedes and turnips a few cwt.—often as little as 1 cwt.—of phosphate makes all the difference between no crop at all and a good crop. (See illustration on page 96). On pastures, especially in the moister parts of the North Island, the effect of a dressing of basic slag is phenomenal; while phosphatic fertilisers* appear to be the most practicable method of treating country where "bush-sickness" prevails. For potatoes, mangels, and generally for all root and fooder crops phosphates are essential, and there is no doubt of their profitable employment even for cereal crops, such as wheat and oats. So effective are phosphatic fertilisers in this

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* See page 22 and 117.

country that one must conclude that there is in our soils an absolute deficiency of phosphates, or at least of phosphates in a form available for plant use. This is the more remarkable in that most of our soils—and especially those in the South Island—have more than Dr. Dyer's* limit of 0·01 per cent. of so-called "available" phosphoric acid, as determined by treatment with 1 per cent. citric acid solution. The total quantity of phosphate in the soil—what we have called the "reserve"—is, however, small in comparison with the reserves of nitrogen and potash. Unfortunately, too, it is phosphate which is retained in greatest amount by the growing animal for the formation of bone, so that when we grow grasses and clovers, roots and rape, and such crops, and on them fatten lambs or rear cattle, we are drawing heavily upon the very constituent which our soils are least able to provide. Finally, there is no indirect method of replacing the phosphate we remove, and no substance that we can apply as a substitute, so that for the maintenance of fertility in this respect we *must* resort to phosphatic manures such as rock phosphates and guanos, superphosphate, basic slag, bone dust, etc.

### Summary of Operations.

We may now collect together the following summary of operations, by means of which the fertility of our farms is raised to and maintained at a high level.

(1) Drainage (if necessary), subsoiling, the growth of deep-rooted pasture plants, and deep ploughing to open up new food supplies.

(2) Feeding off of root and forage crops, such as turnips and rape; consumption on the land of straw, and the spreading of the residue; the ploughing in of

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* Dr. Bernard Dyer, an English agricultural chemist.

the leaves of the mangel crop, and, where convenient, of all refuse such as leaves, hedge-clippings, etc.

(3) Securing good pastures containing a sufficient proportion of clovers and other leguminous plants, so that by the ploughing under of the resultant turf the soil will be enriched with the humus so necessary to bacterial life, as well as with nitrogen gained from the air.

(4) Green-manuring periodically if local conditions make it practicable, if possible using leguminous crops for the purpose.

(5) A heavy dressing of lime to encourage clovers and generally to "sweeten" the soil where clovers are naturally backward and the land is "sour."

(6) Light dressings of lime as substitute for the very expensive potash salts. (Salt applied to mangels and the sulphate of lime that makes up about 50 per cent. of superphosphate act in the same direction.).

## Chapter V.

# THE SOILS OF NEW ZEALAND.

All that has been attempted in this chapter is a very general description of the various soils to be found in New Zealand. A detailed account would require a volume to itself, and even then, so great may be the differences between the soils of various districts, adjoining farms, and even between different portions of the same farm, that it would be impossible to furnish the reader with practical guidance as to the quality, properties and treatment ot soils in any particular locality.

## A.—General Description.

According to methods that have been standardized by their use in Great Britain, it is customary to classify soils according to their geological origin. The application of such methods to our soils is difficult for the reason that the greater portion of our cultivated soils are not *in situ,* but have been transported by river action from their place of origin to their present situation. In this process materials from different geological formations have frequently become mingled together, and during deposition the whole mass has been sorted over by the action of running water and re-arranged according to size in beds of sand, silt, and so on. On account of the different capacities of these materials for supplying moisture, it frequently happens in districts of only moderate rainfall that soils of the same geological origin have widely different agricultural properties and possibilities.

Climatic conditions, past as well as present, and among them especially the distribution of rainfall, are factors that have played a most important part in producing in soils of similar origin modifications that make them wholly different from an agricultural viewpoint. So many and diverse are the factors bringing about differences in soils that no attempt at a complete classification into groups, and subdivision into types can yet be made; and it will be sufficient here to describe shortly some of our more important soil formations.

1. *Alluvial Soils.*—Soils of alluvial deposition are met with on the plains throughout the country, as for example, those of Southland, of the Tokomairiro and Taieri in Otago, of Canterbury, of the Wairau in Marlborough, the Waimea in Nelson, and the Manawatu and Wairarapa in Wellington; and large areas in Hawke's Bay and in Auckland Province come in the same category. Most of the soils mentioned above are formed of the greywacke rock that forms the mountain axis in both islands, but the soil-forming rocks of the Southland Plain include igneous rocks from the western mountains, while the Otago soils are mainly derived from mica schist.

2. *Swamp Soils.*—Many areas of alluvial soils are at such a low level as to be waterlogged when in their natural condition. These areas occur mainly in the lower part of river basins or at the margin of lagoons, and have at some time carried a luxuriant growth of flax, reeds, etc., which decays, and, in the absence of a free air supply, gives rise to sour conditions. These soils all agree in requiring draining, consolidating, and liming to fit them for agricultural development.

Two distinct types of these swamp lands occur, besides, of course, tracts that are intermediate in character between the two extremes. The characteristic vegetation materially helps in distinguishing the two types.

(*a.*) Swamps proper and intermediate types, *e.g.*, Kaitaia, Northern Wairoa, Hikurangi, Rangitaiki, Ngaire, the Manawatu swamps Moutoa and Makerua, Wairarapa, land surrounding the mouths of Canterbury rivers as well as the Taieri, Catlins, and Mataura further south, distinguished in the swamp stage by the presence of flax, cabbage tree, nigger head, cutty grass, and raupo. These lands are of high agricultural value, being usually rendered fertile by drainage alone.

(*b.*) Bog areas or peaty swamps. Some of the swamps previously mentioned include bog areas, *e.g.*, North Auckland swamps, but typical tracts of bog occur at the southern end of the Piako swamp, Rukuhia, and other Waikato swamps, and many small areas of the Auckland gum lands, distinguished by the presence of moss, bracken, tea-tree, rushes, sedges, and frequently sundews. These lands require a relatively lengthy and costly treatment, including deep draining, clearing, liming, phosphatic fertilising, consolidating, and limited cropping, before they can be successfully laid down in permanent pasture.

3. *Volcanic Soils.*—Soils of a volcanic origin are for the most part scattered in isolated patches, as at Dunedin, and in the district to the North, on Banks Peninsula, in Taranaki, and in North Auckland, where the rich vegetation on the volcanic slopes is in marked contrast with that of the clays of the Northern Peninsula. In the central plateau of the North Island, and especially in the Taupo region, is an area of pumice country, covered in a native state by tea-tree scrub and bracken, which for many years was regarded as worthless for agricultural purposes but which, when certain amendments have been made in the soil, principally in the direction of liming and green manuring, has grown certain crops, such as oats, rape, turnips, pasture, and stone fruits quite well.

4. *Limestone Soils.*—There are numerous areas of limestone soils in this country which, when the rainfall is sufficient, are noted for their fertility. In Southland there is a discontinuous limestone band

from Fairfax to Winton; in Otago, Milburn in the south, and Oamaru in the north are the centres of important areas. Limestone soils are found in the Pareora District near Timaru, and in the Weka Pass district in North Canterbury, and a large area further north at Amuri. Southern and eastern Marlborough is also largely limestone country. Considerable tracts also occur in the Wairarapa, while a large portion of Hawke's Bay is underlain by limestone, and many patches occur in Auckland Province. Many other localities could be mentioned, but most of the areas susceptible to cropping have been referred to.

5. *Papa Soils.*—Papa is a blue calcareous clay occurring mainly in the North Island, where it takes a prominent part in the formation of the raised coastal plain of the West Coast, and is found under extensive tracts of soil in Hawke's Bay. Near Wanganui and in southern Taranaki beds of sand and clay are also involved in the papa formation, especially on the seaward margin; while inland, beds of shelly limestone are also interspersed. Soils derived from papa give very good and lasting pasture, and to their presence may be mainly attributed the success attained by these districts in sheep production.

6. *Pastoral Country.*—Of the 40,000,000 acres of occupied land in New Zealand according to last census, 24,000,000 acres are unimproved native grass and bush, while of the remainder over 9,000,000 acres are in grass surface sown on bush burns, and will not come under the plough for many years. Thus pastoral country forms an important part of the total soil area. The conditions preserving the existence of such a large proportion of only partially improved land are mainly two: (1) the land is either too broken or too light for profitable cultivation; (2) the cost of clearing the stumps of the burnt forest is prohibitive

under present conditions of labour. It follows that the increasing of the productivity of such land is not a matter of finding crops and rotations suited to the conditions, but of discovering the best system of getting and maintaining a covering of grass.*

7. *Abnormal Areas.*—There are in New Zealand several important areas where the conditions are abnormal from an agricultural standpoint. Among such are the following:—

(*a*) Pakihi Soils of Westland, which occur over considerable tracts of sour, swampy, but easily drained terrace lands. It has been shown by Mr. Aston that these soils have a high percentage of magnesia compared with that of lime, and that they are also deficient in phosphates. In addition to draining they therefore require heavy dressings of lime and basic slag before they can be cultivated profitably.

(*b*) Arid Regions.—The only lands that can be classed as arid are found in parts of the Mackenzie Country and Central Otago, where the average annual rainfall is from 14 to 20 inches. In these areas the soil is for the most part fertile; its better development presents irrigation problems in some parts, and everywhere demands careful study to decide upon the pasture mixtures best suited to the conditions.

(*c*.) The gum lands of North Auckland consist mainly of

- (*a*.) swamps and bogs (see page 50);
- (*b*.) sandy clays;
- (*c*.) clays.

The sandy clay which is the predominant type is really a loam practically devoid of organic matter.

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*See "Pasture Plants and Pastures of New Zealand," by Dr. F. W. Hilgendorf in this series.

It is rich in potash but markedly poor in phosphates and nitrogen. With the application of phosphatic manures such as basic slag and lime, clovers and lotus thrive. *Lotus hispidus* and *L. angustissimus* are successful on the drier areas, while *L. major* is suited for damp situations. These legumes are of great value, particularly on cultivated areas, in augmenting the content of nitrogen and organic matter and thereby enabling a good pasture mixture to be established. Red clover, ryegrass, maize, millet, lucerne, and fruit, have all been successfully grown. A problem awaiting solution is the increase of the clover content of unploughable pasture with a view to the improvement of the content of nitrogen which it is scarcely practical to supply in the form of highly priced nitrogenous fertilisers.

The clays respond to much the same treatment as the sandy clays except that they are more intractable. Indeed the elevated clays which are prone to dry out during the summers are suitable for little except second class pasture.

Both the sandy clays and the clays benefit markedly from drainage. Indeed, it has been found advisable to lay underground drains on sloping country where to all appearances the natural drainage should be sufficient.

(*d*) Stony Lands.—In the South Island especially are considerable areas of stony soil—not light sandy land of a hungry type, for between the boulders is soil of good quality and containing a not too low proportion of clay. It is the boulders that constitute the chief obstacle in the way of their successful cultivation, and when machinery is available for clearing these satisfactorily, the soil will be found quite suitable for cropping. At present very much of such land is occupied by poor thin pasture.

## B.—Physical and Chemical Characteristics.

The cultivated soils of New Zealand vary from medium light to medium heavy in texture, for population is not yet dense enough to force settlers on to the very light sandy land (of which there is some 400,000 acres), nor to the extreme types of clay, to cultivate which successfully requires knowledge that comes only of long, and often bitter, experience.

**Auckland Province** contains a greater variety of soils than any other in New Zealand. The gum lands and volcanic areas have already been described. These lands have great potential wealth, and await development. The great valleys of the Waikato, Piako, and Thames are filled with detritus from the pumice of the central plateau. The fall of these basins is very slight; large areas are swamps or reclaimed swamps, (see pages 50-51), and require draining and liming, but after that phosphatic manures bring them into a condition of high productivity. The pumice lands of the Taupo region have already been described (page 51). In the Bay of Plenty district much of the land is still heavily timbered, and so also in the East Cape country. The climate is mild, the rainfall heavy, and where arable land is found maize is a notable crop. On the West Coast the country is only slowly being cleared of timber, and owing to heavy rainfall and lack of metal communications are bad; but South-west Auckland has great possibilities, since some of the best dairying land in Taranaki has similarly been carved out of the rain forest. As a general rule Auckland soils require heavy manuring, and analyses show that phosphates in particular are deficient.

**Poverty Bay** is mainly rich pastoral country, and carries good grass. The plains and downs of **Hawke's Bay** cover such limestone, papa, and alluvial country, and their soils are good both for cropping and for grass, but the dry spell in summer makes dairying a precarious undertaking.

On the west coast, the soils of **South Taranaki** are lighter, and require more feeding. They overlie beds of papa and calcareous sandstones, but between these and the soils are gravels and sands that are not producers of rich soils. However, with proper manures, and especially with a system of green-manuring, which the copious rainfall makes easily possible, excellent yields of all crops subsidiary to dairying, such as maize, mangels, lucerne, oats, peas, etc., are readily grown. Taranaki has a very wide reputation as dairying country, and its butter and cheese factories are amongst the finest in the Empire.

On the west of **Wellington** is a raised coastal plain that was once heavily timbered but has yielded to axe and fire, and now is very fine grazing country, supporting a number of rapidly rising towns. The Rangitikei and Manawatu rivers have built gravel plains covered with soil of great productivity, where dairying is practised extensively. On the eastern slope of the dividing range to the south of Woodville and along the Wairarapa railway is a long stretch of limestone country formerly forest clad, and now occupied by prosperous sheep and cattle runs. The Wairarapa Plain is stony in parts, but on the whole the soils are good, and the area is noted for its production of wool, mutton, dairy produce, and grain. Except for the fertile Hutt Valley the rest of Wellington Province is mainly pastoral country. The narrow eastern coastal strip is poor country where scrub has proved to be difficult to eradicate.

**Nelson** is a province that presents some rather unusual features. The climate is extremely mild and sunny, while the rainfall is quite sufficient. Hops are a notable crop, while considerable areas are being taken up for fruitgrowing. In several parts the soils contain an excess of magnesia, and refuse to produce ordinary crops until good dressings of lime have been applied. In this respect they resemble the "Pakihis"* of **Westland** which, however, require draining as well. The coastal plains of Westland are for the most part clothed in valuable forest, but when this has been removed, they will, with drainage, lime, and phosphates, carry satisfactory pasturage.

Southern **Marlborough** suffers from its inaccessibility. There is much limestone country there covered by four to six inches of very fertile soil. It is mainly pastoral country, but is obtaining some reputation for its lucerne, which evidently finds a suitable environment. The plain of the Wairau is an area of exceptional fertility; though low-lying, the danger of floods has been localised by overflow channels and by a system of embankments. The district is "the home of lucerne," and produces the finest seed of that plant obtainable in this country; it also yields excellent malting barley; large quantities of peas, more especially of garden varieties; mangels, cowgrass, and oats. Climate and soil seem exceptionally well adapted to seed production. In this, as well as in other parts of Marlborough, dairying and fruit-growing are practised.

From the Waipara, in the north, to the Opihi, near Timaru, stretch the great **Canterbury Plains**, widest about Rakaia and narrowing at either extremity where the foothills close in to the coast. They have been formed of the gravels, sand, and silt brought from the mountains by the rivers and spread out along the coast, and in some parts are smeared over with a layer of wind-borne loess that rises on Banks Peninsula to a height of some 800 feet. The main types of country met with are three: (1) The light and sometimes stony country bordering the foothills; in North Canterbury is an area of some 80,000 acres of manuka and other scrub awaiting reclamation.

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*See page 53:

(2) The typical, originally tussock-covered plains land, the soils of which vary from light and stony, as at Burnham, to heavy silts as at Ashburton. (3) The swamp areas along the coast in the vicinity of the river mouths. The second type of soil responds immediately to the plough and seed-drill; the third requires draining and probably liming. Both require phosphates, and respond best to basic phosphates; between them they yield two-thirds of the wheat grown in New Zealand. Canterbury soils are as a whole among the most productive in New Zealand, growing well wheat, oats, barley, peas, mangels, turnips, and rape, and the province has given its name to the highest grade of mutton and lamb exported from our shores.

In North Canterbury a large area of land is underlain by limestones, green sands, and yellow shelly sandstones. Most of this country is hilly; it has no good and convenient outlet by sea; it has been taken up in large holdings; hence it is mainly pastoral country. The limestones and green-sands yield very rich soils. At Waikari soil and climate combine to produce the finest milling wheat in the country—but the soils from the sandstones, besides being for the most part too broken for the plough, are poorer in plant food. Nevertheless they yield good sweet natural pasture.

In **South Canterbury** is an area of phenomenal fertility round Willowbridge, where are soils that have been cropped for over 40 years without manuring until quite recently. Heavy yields of excellent wheat are harvested; also oats, and, especially at Willowbridge, potatoes. Waimate, besides producing good grain, is noted for its supplies of fruits such as strawberries and raspberries. The soils of the Timaru Downs are heavy clays derived from wind-borne deposit termed loess. To the west the Pareora Downs have a good deal of limestone and sandstone, but most of this country is too broken for ploughing. Further inland the Mackenzie Country is also pastoral country. It lacks a sufficient rainfall, and its soils have proved to be difficult to grass satisfactorily. Experiments by the Department point to the futility of surface sowing, and the necessity of drilling in suitable mixtures of deep-rooted grasses and forage plants.

A variety of soils is met with in **Otago**. The Tokomairiro Plain is an area of considerable fertility, and has at its inner end the limestones and rock phosphate of Milburn and Clarendon. The Taieri Plain has also been noted for its wealth ever since it was reclaimed by drainage from its original swampy condition. The soils are derived from the schist rock of Central Otago, and are well supplied with plant food, but are responsive to liming. Both these plains yield good crops of wheat of fair quality; likewise heavy crops of oats, turnips, and grass. Central Otago is mainly pastoral country, though the climate has proved admirably adapted to fruit growing, and a considerable industry exists. The schist rock yields a soil rich in potash for the most part in an available condition, and other constituents are not lacking. The districts through which the Heriot railway passes are, however, not rich, and their soils would respond to both liming and green manuring. In North Otago areas of limestone and associated Tertiary rocks, such as green and yellow sandstones and marls, occur in the Oamaru district. The soils are fairly good, but the deficient rainfall (about 20 inches per annum) is a serious drawback.

In **Southland** the soils vary from medium to heavy in texture, the average of analyses yielding about 25 per cent. of the finer fractions, fine silt and clay, and about 25-40 per cent. of sand. The amount of coarse silt is 20-35 per cent. The soils of the river-flats are heavier than those of the plains, but having a more open subsoil and good natural under-drainage, they are usually warmer and sweeter, and consequently more productive. The average percentages of phosphoric acid, potash, lime, nitrogen, and organic matter of some typical soils are shown in the table at the end of this section, along with the corresponding figures for the other soil districts. Most of the plains soils stand in great need of lime, and give a most gratifying response to its application, especially in the eastern districts. This seems to be due to the heavy impervious subsoil and the high rainfall of the district combining to prevent æration, and therefore oxidation, of organic matter, in consequence of which "sour" humus accumulates in the soil. Oats and swedes are the main crops taken, and both give high yields of excellent quality. Wheat is grown on the Dipton Flat of the Oreti, the Bayswater Flat of the Aparima, and in the Garston District, south of Kingston; but the husk is too thick for high grade milling wheat. The pastures of ryegrass and clover are truly evergreen.

In the Catlins River district are soils of great natural fertility, but they require both lime and organic matter to bring them into a condition of really high productivity. They have been described by Aston in the *N.Z. Journal of Agriculture*, Vol. III., No. 6.

### Summary of Soil Analyses.

The following table summarises what is known by analysis of the average mechanical and chemical constitution of the soils from the various areas mentioned above. By far the most of these analyses are those of Mr. Aston; the rest are those of Mr. Gray,* or of the author, or his students. It must be understood that the number of analyses made of soils

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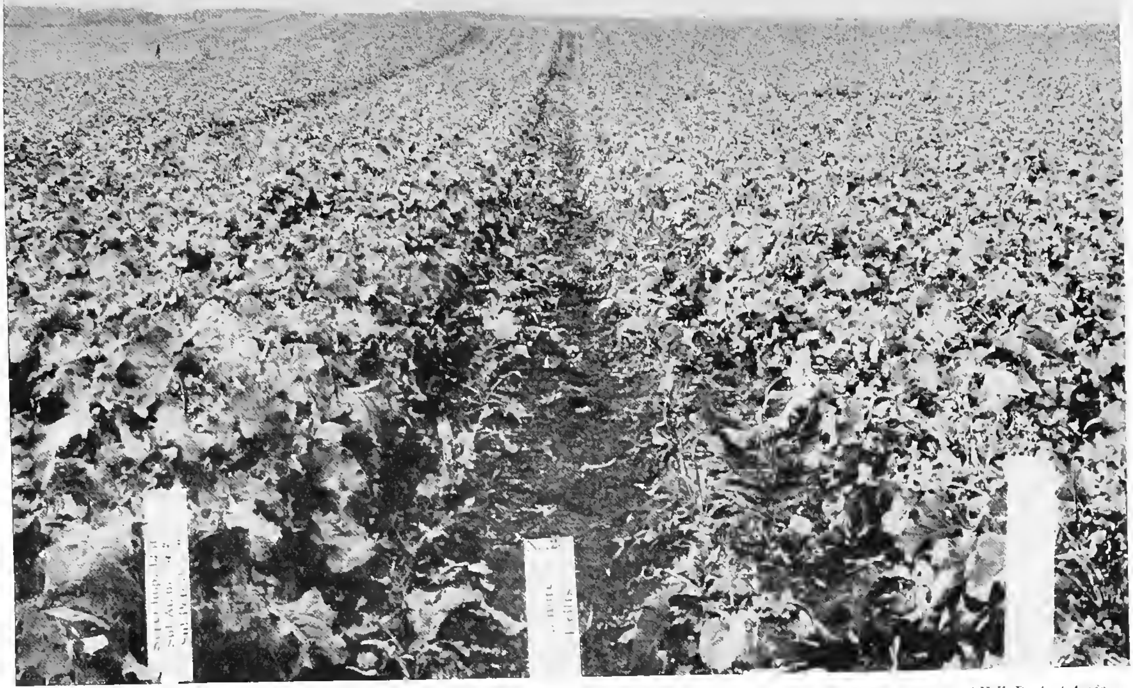
*Formerly chemist at Canterbury Agricultural College, Lincoln.



*(By kind permission of N.Z. Dept. of Agric*

Manuring of Swede Turnips. Left and right sides, complete manure. Centre rows, no manure.
(See also illustration on page 96)

| DISTRICT. | No. of Analyses | Hygroscopic Moisture | Loss on Ignition | Nitrogen | Sol. in Citric Acid | | | Sol. in str. HCL | | | | | Mechanical Analysis | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | No of Analyses | $K_2O$ | $P_2O_5$ | No. of Analyses | CaO | MgO | $K_2O$ | $P_2O_5$ | No. of Analyses | Coarse Fractions | Inter-mediate Fractions | Fine Fractions |
| North Auckland | 30 | 7·62 | 11·42 | ·304 | 36 | ·020 | ·009 | 11 | ·214 | ·205 | ·186 | ·075 | 20 | 48·8 | 9·6 | 35·8 |
| Central Plateau | 2 | 7·55 | 13·54(7) | ·381 | 10 | ·025 | ·040 | 3 | ·33 | ·24 | ·14 | ·16 | 2 | 61·7 | 7·7 | 15·3 |
| Bay of Plenty . . | 3 | 7·36 | 14·76 | ·368 | 3 | ·014 | ·023 | 3 | ·48 | ·19 | ·11 | ·18 | 3 | 74·8 | 7·4 | 14·5 |
| Taranaki . . | 8 | 10·06 | 18·15 | ·629 | 8 | ·019 | ·027 | 4 | ·39 | ·08 (1) | ·15 | ·25 | 7 | 69·4 | 6·1 | 17·8 |
| Hawke's B. Plns | 15 | 7·46 | 11·5 | ·313 | 15 | ·025 | ·019 | 7 | ·41 | ·24 | ·17 | ·12 | 14 | 64·0 | 7·6 | 23·1 |
| ,, Pastoral | 4 | 6·47 | 12·05 | ·366 | 4 | ·025 | ·025 | . . | . . | . . | . . | . . | . . | . . | . . | . . |
| Upper Wairarapa | 7 | 8·7 | 13·9 | ·435 | 7 | ·019 | ·023 | 5 | ·49 | ·45 | ·15 | ·17 | 7 | 55·1 | 9·4 | 29·0 |
| Lower Wairarapa | 8 | 5·31 | 9·04 | ·258 | 8 | ·018 | ·018 | 2 | ·29 | ·39 | ·22 | ·11 | 7 | 52·6 | 8·6 | 34·4 |
| West C. Plains | 23 | 6·49 | 10·28 | ·302 | 23 | ·018 | ·013 | 15 | ·38 | ·28 | ·18 | ·14 | 22 | 60·7 | 8·2 | 24·9 |
| Wgton. Pastoral | 14 | 7·76 | 10·63 | ·385 | 14 | ·020 | ·035 | 3 | ·57 | ·27 | ·16 | ·26 | 16 | 62·8 | 6·8 | 21·8 |
| Marlborough, Wairau Plain | 8 | 4·02 | 7·56 | ·299 | 8 | ·051 | ·049 | 6 | . . | . . | ·41 | ·17 | 8 | 29·4 | 20·6 | 38·8 |
| Other Districts | 5 | 3·00 | 7·14 | ·228 | 5 | ·022 | ·017 | 2 | ·58 | . . | ·28 | ·15 | 5 | 53·2 | 10·4 | 33·6 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nelson, Waimea Plains | 2 | 2·50 | 6·25 | ·153 | 2 | ·015 | ·023 | .. | .. | .. | .. | .. | 2 | 41·4 | 8·9 | 49·4 |
| Other Districts | 9 | 4·87 | 10·11 | ·230 | 9 | ·012 | ·014 | 8 | ·68 | 2·84 | ·17 | ·09 | 8 | 57·2 | 11·3 | 25·6 |
| Westl'd, Pakihis | 5 | 4·26 | 8·76 | ·230 | 5 | ·060 | ·006 | 3 | 0·11 | ·043 | ·082 | ·0017 | 5 | 54·5 | 16·9 | 25·1 |
| Other Districts | 8 | 3·42 | 5·32 | ·162 | 5 | ·012 | ·046 | 1 | ·07 | ·10 | ·09 | ·016 | 6 | 54·3 | 11·9 | 26·0 |
| Mid-Canterbury Plains .. | 31 | 3·32 | 7·18 | ·222(24) | 8 | ·018 | ·031 | 35 | ·53 | ·36 | ·25 | ·15 | 15 | 42·6 | 25·7 | 26·5 |
| S'th Canterbury | 18 | 3·04 | 7·21 | ·235 | 14 | ·023 | ·023 | 16 | ·55 | ·31 | ·26 | ·16 | 15 | 51·0 | 13·8 | 29·5 |
| N'th Canterbury | 5 | 3·40 | 6·76 | ·219 | 2 | ·015 | ·009 | 8 | ·26(3) | ·41(3) | ·41 | ·18 | 5 | 39·9 | 22·2 | 25·4 |
| Cantby., Pastoral | 8 | 3·34 | 7·60 | ·210 | 6 | ·018 | ·024 | 6 | ·51 | ·41 | ·25 | ·12 | 7 | 50·7 | 18·3 | 26·5 |
| ,, Swamp .. | 6 | 2·55 | 4·50 | ·161 | 2 | ·017 | ·046 | 6 | ·61 | ·61 | ·27 | ·12 | 1 | 31·9 | 31·6 | 30·6 |
| North Otago .. | 7 | 5·51 | 10·39 | ·339 | 7 | ·018 | ·039 | 6 | ·62 | ·87 | ·32 | ·21 | 3 | 57·0 | 9·9 | 30·3 |
| Central Otago .. | 29 | 3·21 | 5·28 | ·199 | 29 | ·016 | ·028 | 15 | ·35 | ·48 | ·20 | ·17 | 24 | 58·5 | 11·5 | 26·5 |
| South Otago .. | 9 | 4·64 | 7·92 | ·230 | 9 | ·014 | ·017 | 6 | ·33 | ·33 | ·20 | ·11 | 8 | 62·5 | 6·8 | 27·6 |
| Southland Plains | 12 | 4·21 | 10·89 | ·290(4) | 2 | ·017 | ·015 | 10 | ·37 | ·55 (3) | ·16 | ·15 | 9 | 39·7 | 33·6 | 18·6 |
| ,, River Flats | 6 | 3·03 | 8·49 | ·288(2) | 2 | ·018 | ·011 | 5 | ·94 | .. | ·14 | ·10 | 9 | 34·0 | 24·3 | 36·4 |

NOTE.—Figures in brackets indicate number of analyses for that particular constituent.

of any one district is in most cases quite insufficient to characterise the soils definitely, and for that reason the number of analyses represented by the average given is indicated. The more analyses, of course, the more useful the figure given.

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## CHAPTER VI.

# HOW TO FIND THE MANURIAL REQUIREMENTS OF A SOIL.

It is only within the last hundred years that chemical analysis has given us definite knowledge of the food requirements of plants. About 1840 the chemist Liebig, in what later became known as the Law of the Minimum,* laid it down that a soil is incapable of producing a crop if it is deficient in any single necessary constituent of that crop, even though the other constituents are present in abundance; and ever since that time the question that has received most attention at the hands of agriculturists has been how to discover the deficiency of soils in the elements of plant nutrition, and how best to remedy the deficiency.

The various methods that have been tried in the endeavour to answer this important question of the relative fertility of soils may be treated under the following heads:—A. Analytical methods. B. Pot experiments. C. Plot experiments.

### A.—Analytical Methods.

Soil analysis is of two kinds: Chemical analysis, which shows the quantities of the various elements soluble in strong acids; and mechanical analysis, which reveals the relative proportions of sand, silt, clay, etc.

It was natural that chemists who had at their command refined methods of analysis and a steadily increasing knowledge of the composition of the various field crops, should believe that the chemical analysis of a soil would at once indicate the elements it lacked, or in other words, the nature and quantity of its manurial requirements. Such hopes were, however, doomed to disappointment, as a consideration of the following figures would lead one to imagine.

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* See pages 23 and 30.

The Table A. displayed below shows the requirements of the principal soil constituents in lbs. per acre on the part of average farm crops.

TABLE A.—WEIGHT AND AVERAGE COMPOSITION OF ORDINARY CROPS IN POUNDS PER ACRE.

| CROP | Nitrogen | Potash | Lime | Phosphoric Anhydride | Magnesia |
|---|---|---|---|---|---|
| Wheat, 30 bushels .. | 34 | 9·3 | 1·0 | 14·2 | 3·6 |
| Straw, 1½ tons .. | 16 | 19·5 | 8·2 | 6·9 | 3·5 |
| Barley, 40 bushels .. | 35 | 9·8 | 1·2 | 16·0 | 4·0 |
| Straw 2,450 lbs. .. | 14 | 25·9 | 8·0 | 4·7 | 2·9 |
| Oats, 45 bushels .. | 34 | 9·1 | 1·6 | 13·0 | 3·6 |
| Straw, 2,835 lbs. .. | 18 | 37·0 | 9·8 | 6·4 | 5·1 |
| Meadow Hay, 1½ tons | 49 | 50·9 | 32·1 | 12·3 | 14·4 |
| Turnips, roots, 17 tons | 61 | 108·6 | 25·5 | 22·4 | 5·7 |
| Leaves, 5 tons .. | 49 | 40·2 | 48·5 | 10·7 | 3·8 |
| Mangels, roots, 22 tons | 98 | 222·8 | 15·9 | 36·4 | 18·3 |
| Leaves, 9 tons .. | 51 | 77·9 | 27·0 | 16·5 | 24·2 |
| Potatoes, tubers, 6 tons | 46 | 76·5 | 3·4 | 21·5 | 6·3 |

The next table shows the percentage and weights per acre of nitrogen, potash, and phosphoric anhydride in some of our soils, assuming that an acre of soil 8in. deep weighs 2,000,000 lbs. The table on page 62 can also be used for comparison.

## TABLE B.—QUANTITIES OF NITROGEN (N), POTASH ($K_2O$) AND PHOSPHORIC ANHYDRIDE ($P_2O_5$) IN SOME NEW ZEALAND SOILS.

| LOCALITY. | Total Nitrogen | | Potash ($K_2O$) | | | | Phosphoric Anhydride $P_2O_5$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Available | | Reserve | | Available | | Reserve | |
| | Percentage | Lbs. per acre | Percentage | Lbs. per acre | Percentage | Lbs. per acre | Percentage | Lbs. Per acre | Percentage | Lbs. per acre |
| Auckland | ·44 | 8800 | ·018 | 360 | ·11 | 2200 | ·036 | 720 | ·19 | 3800 |
| Ruakura | ·337 | 8740 | ·022 | 440 | ·24 | 4800 | ·017 | 340 | .. | .. |
| Cambridge | ·219 | 4380 | ·048 | 960 | ·24 | 4800 | ·006 | 120 | ·14 | 2800 |
| Hamilton | ·298 | 5960 | ·078 | 1560 | ·14 | 2800 | ·139 | 2780 | ·45 | 9000 |
| Hastings | ·211 | 4220 | ·008 | 160 | ·21 | 4200 | ·007 | 140 | ·06 | 1200 |
| Kopua | ·340 | 6800 | ·020 | 400 | ·26 | 5200 | ·028 | 560 | ·25 | 5000 |
| Norsewood | ·471 | 9420 | ·010 | 200 | ·09 | 1800 | ·016 | 320 | ·13 | 2600 |
| Stratford | ·562 | 11240 | ·013 | 260 | .. | .. | ·026 | 520 | .. | .. |
| New Plymouth | ·766 | 15320 | ·025 | 500 | ·23 | 4600 | ·014 | 280 | ·27 | 5400 |
| Marton | ·337 | 6740 | ·020 | 400 | ·21 | 4200 | ·012 | 240 | ·28 | 5600 |
| Feilding | ·343 | 6860 | ·021 | 420 | ·16 | 3200 | ·020 | 400 | ·18 | 3600 |
| Waimarino | ·730 | 14600 | ·025 | 500 | ·09 | 1800 | ·043 | 860 | ·44 | 8800 |
| Eketahuna | ·314 | 6280 | ·013 | 260 | ·10 | 2000 | ·014 | 280 | ·09 | 1800 |
| Blenheim | ·114 | 2280 | ·046 | 920 | ·42 | 8400 | ·035 | 700 | ·19 | 3800 |
| Seddon | ·223 | 4460 | ·016 | 320 | .. | .. | ·021 | 420 | .. | .. |
| Bainham | ·238 | 4760 | ·010 | 200 | ·21 | 4200 | ·012 | 240 | ·10 | 2000 |
| Appleby | ·182 | 3640 | ·012 | 240 | ·36 | 7200 | ·020 | 400 | ·15 | 3000 |
| Lincoln | ·285 | 5700 | ·031 | 620 | ·20 | 4000 | ·033 | 660 | ·116 | 2320 |
| Ashburton | ·252 | 5040 | ·026 | 520 | ·14 | 2800 | ·010 | 200 | ·13 | 2600 |
| Timaru | ·098 | 1960 | ·011 | 220 | ·30 | 6000 | ·034 | 680 | ·15 | 3000 |
| Waimate | ·194 | 3880 | ·015 | 300 | ·21 | 4200 | ·017 | 340 | ·10 | 2000 |
| Westport | ·196 | 3920 | ·011 | 220 | ·09 | 1800 | ·004 | 80 | ·016 | 320 |
| McKenzie Country | ·208 | 4160 | ·011 | 220 | ·28 | 5600 | ·012 | 240 | ·11 | 2200 |
| Palmerston | ·224 | 4480 | ·010 | 200 | ·32 | 6400 | ·009 | 180 | ·06 | 1200 |
| Balclutha | ·180 | 3600 | ·007 | 140 | ·25 | 5000 | ·013 | 260 | ·08 | 1600 |
| Tapanui | ·230 | 4600 | ·01 | 200 | ·12 | 2400 | ·019 | 380 | ·10 | 2000 |
| Gore | ·250 | 5000 | ·018 | 360 | ·20 | 4000 | ·010 | 200 | ·13 | 2600 |
| Edendale | ·351 | 7020 | ·017 | 340 | ·15 | 3000 | ·021 | 420 | ·10 | 2000 |
| Barkly | ·284 | 7680 | ·014 | 280 | ·19 | 3800 | ·011 | 220 | ·06 | 1200 |

It is at once seen that these soils contain enough of the elements to provide many times over for a rotation of wheat, oats, turnips, and three years' grass, even without manures. Yet we know that manures pay handsomely on all these soils, and are absolutely necessary on some of them. Furthermore the analyses do not tell us why it is that the Blenheim and Morven soils, for example, will continue to yield satisfactory crops without fertilisers, while Ruakura soil without manuring will scarcely pay for cultivation. Facts of this sort soon showed that the soil compounds containing the elements of fertility are not so simple and readily available to plants as those added as manures, and various attempts were then made to find a practical interpretation of the figures obtained by analysis. The most promising suggestion was that possibly some definite fraction of the total amount of any mineral was accessible to plants, and it was tried to discover what this fraction might be. But it was found impossible to fix a definite ratio between the food immediately available to plants and the total amount of plant food present in the soil, for even one element in the case of even one variety of plant growing on even one type of soil — still less to arrive at a ratio of general application. A more reasonable suggestion was that, already quoted,* of Dr. Dyer, who, investigating the food supplies in the Hoos Field of Rothamsted Experimental Station in England, whereon barley had been grown for forty years, discovered that a 1 per cent. solution of citric acid was able to dissolve out a much greater amount of phosphate from the plot that had received annual dressings of phosphatic manures than from the plots that had received only potash and nitrogen, or no manure at all. He showed that in this field soils suffering from phosphate starvation yielded less than about 0·01 per cent. of phosphoric acid, and those suffering from potash starvation less than about 0·005 per cent. of potash in solution in citric acid. Many other weak acids have been tried in the hope of discovering one capable of imitating exactly the imagined solvent power of the root-hairs of plants, but in British countries Dyer's method has been most used. It is doubtful whether its author expected it to be put to general use, and it is certain that it is not capable of satisfactory application in New Zealand. Who, indeed, would reason that because a method is capable of indicating lack of certain elements in a soil cropped without manures for forty years, it should, therefore, be capable of displaying the fertility of our comparatively new and naturally rich New Zealand soils? The following illustrations will suffice:—(1) The average of three analyses of Ruakura Experimental Farm soils shows 0·025 per cent. of phosphoric acid soluble in citric acid solution; yet these soils give an amazing response to phosphatic fertilisers. (2) The soils of the Lincoln College Farm contain an average of 0·03 per cent. of so-called "available" phosphoric acid, yet the practice there is to use phosphatic fertilisers with all crops; even wheat, a plant specially able to forage for itself, receives 1 cwt. of basic superphosphate per acre. (3) The following averages are from figures taken from the *N.Z. Journal of Agriculture*, recording the results of manurial experiments on seven different soils in Otago and Canterbury. The average percentage of phosphoric acid soluble in citric acid solution was 0·027 per cent., that is, well above Dyer's limit. The average yield of unmanured swedes was 16·4 tons per acre, while the average yield when 1½ cwt. of super. was used was 28·4 tons. (4) Summarising the results of the analyses of 488 New Zealand soils, Mr. Aston finds that 323 or 66 per cent. have sufficient phosphoric acid in an available form according to Dyer's method of reckoning. Taking the analyses for soils from Canterbury, Otago, and Southland, we find only 6 soils out of 136, or only

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* See page 47.

4½ per cent. deficient in this respect. Yet one may say without much fear of contradiction that 70 per cent. of the soils of these three provinces pay handsomely for a dressing of phosphatic manure, and if we consider the whole country at least 80 per cent. of our soils are in this case. (5) We can state one further aspect of the importance of phosphatic manures to New Zealand soils, despite the apparent sufficiency of so-called "available" phosphates already present. Practice usually evolves the best method, and there is no doubt that phosphatic manuring is an important item in New Zealand farming, as the following figures will show. In 1913 there were 1,635,000 acres in crop in this country. In the same year 102,700 tons of phosphatic manures were imported; 10,000 tons (the average annual output) of rock phosphate was mined in Otago; and judging from the export of frozen meat 9000 tons of phosphatic manurial material was available at the freezing works for mixing with the imported stuff. This gives a grand total of 121,700 tons, from which we shall deduct 30,350 tons, the amount of basic slag imported, assuming that it was used only on grass lands. This leaves 91,350 tons available for 1,635,000 acres, which gives an average application of 1.1 cwt. per acre.

In these days the hope is no longer entertained of being able to prescribe the correct manuring for an individual soil from a mere analysis. The fact is that chemical analysis merely shows the amount of potential plant food in the soil, not the quantity that the plant can get out. Moreover no absolute minimum can be fixed even in the case of the more important constituents, for experience shows that an amount that is sufficient in one soil, may be quite inadequate in another. Soil fertility depends on a great variety of factors, of which the supply of soluble minerals is only one. Others, quite as important, are the water relationships of the soil, suitable conditions as regards temperature, a sufficiency of air, absence of injurious factors, and so on, as has been fully discussed in Chapter III. Some of these, especially the conditions as to moisture, air, and temperature, are mainly controlled by the size of the soil particles, the amount of humus, and so on, and of these desiderata a chemical analysis takes no account whatever. In fact, one gets a more comprehensive view of a soil by means of a mechanical analysis, which displays the relative proportions of sand, silt, clay, organic matter, etc., than by a chemical analysis which sheds light on only a small fraction of the soil, to wit, the part soluble in acids.

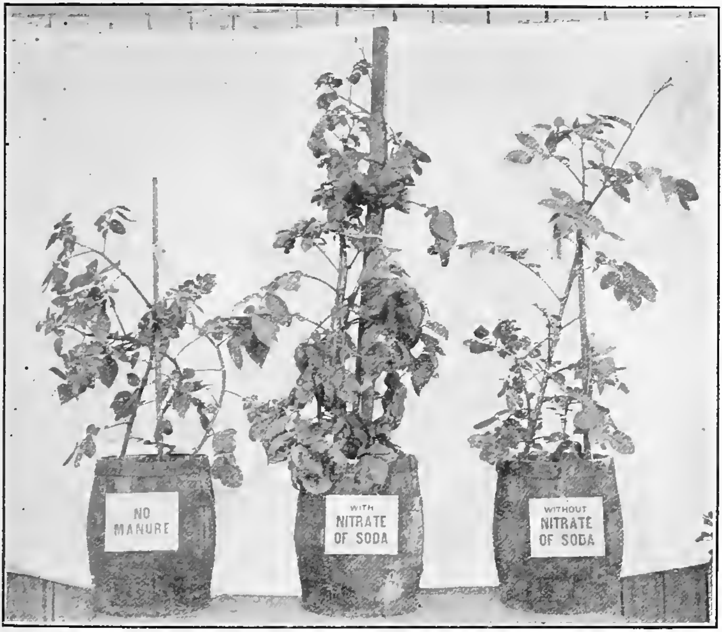
For these reasons soil chemists no longer attempt to find out the manurial requirements of a soil simply by making an analysis of it. All that they can do is to compare the properties of the soil as displayed by mechanical and chemical analysis with those of other soils of similar origin, situation, and climatic conditions, the characters and manurial demands of which are known by experiments. It can then be judged in what way the soil differs from or resembles others of its type, and a fairly satisfactory opinion can then be formed of the method of cultivation and manurial treatment most suited to it. It is obvious, therefore, that the first thing to be done in a given area is to make a complete study of its soils, both in the laboratory, by analytical and other methods, and in the field, by manurial and cultural experiments, and by collecting the conclusions of farmers who have had experience in their management. Such work forms part of a soil survey, and its object is the classification into types of soils of similar origin, composition, and general characters. Unfortunately in

New Zealand little work of this sort has as yet been accomplished, and reliance must meanwhile be placed on the methods to be described in the next sections.

Before leaving the subject of analysis, however, mention should be made of a method that has been tried of analysing the soil by means of the plant. It is based on the assumption that the ash of any crop, grown on soils supplied with normal quantities of plant food, will have a certain typical composition, but that the ash of crops yielded by soils deficient in one or more essential elements will reflect this deficiency in its composition. Analysis shows, however, that the composition of plant ash is much the same, irrespective of the soil on which the plant was grown, and that such variations as do occur from lack of nutritive substances are no greater than those due to seasonal conditions or to differences in the supply of non-essential constituents, such as lime and soda. In general, the composition of the ash of roots, for example, turnips and mangels, was found by Hall to be more affected by changes in soil composition than that of cereals, and, coming to individual cases, he found the ash of mangels grown on unmanured soil to give a good indication of its potash requirements, while the ash of swedes furnished suggestive information as to the necessity or otherwise for phosphatic manuring. Up to the present, however, no entirely satisfactory test plants have been found, and the method is not sufficiently developed for practical application.

### B.—Pot Experiments.

Pot experiments made with proper precautions afford useful information regarding the fertiliser needs of soils. The idea is to treat small quantities of soil with proportionate amounts of various manurial mixtures, place the samples in suitable vessels, and sow in them seeds of the usual crops or grasses. Ordinary flower pots about one foot deep are most suitable, but even boxes such as kerosene cases opened at the side serve quite well. The illustration on page 76 shows the sort of response that



MANURING OF POTATOES—"Satisfaction."
Grown without Manure; and with Super., Sulph. of Potash.
With or without Nitrate of Soda.
Yield of Tubers: 1lb. 2oz. 3lb. 12oz. 2lb. 4oz.

may be obtained from soils dealt with in this manner. It is necessary to weigh out the manures carefully, and to this end a small chemical balance is necessary. The addition of 0.1 gram of manure to one kilogram of soil is about equivalent to 200 lbs. per acre. The fertiliser should be mixed first with a little of the dry soil, and then stirred into the surface soil, but bulky manures should be mixed through the whole sample. Another absolutely necessary precaution is to conduct the trials in triplicate so as to eliminate what is called the experimental error, a matter that is discussed more fully in the next section. An American improvement which is described in Bulletin No. 2 of the Chemistry Division of the N.Z. Department of Agriculture, consists in using wire baskets coated with paraffin, the progress of the crops being measured by the rate of transpiration of water.

The defects of pot or box experiments are the artificial conditions under which they are conducted. The soil is removed from its natural position, and in mixing the fertilisers it receives a better cultivation than farm implements can give it. The pots are maintained at more equable temperatures than obtain in the field, and the water is always carefully regulated. The influences of sub-soil and of precarious weather conditions on the water and air supply and on temperature are eliminated, and consequently attempts to apply the results so obtained to field practice may be disappointing. The kind of result obtainable by means of pot experiments is illustrated by the photographs on pages 73, 76, and 77.

### C.—Plot Experiments.

These form the only satisfactory basis we at present have on which to form an estimate of the needs of a soil as regards manures. They consist simply in treating field plots with various manurial prescriptions, and harvesting and weighing the produce in due season. At every stage the experiment is under natural conditions, the manures and seed are applied by the ordinary implements, and the weather conditions and water supply are not interfered with. Plots of 1-40th to 1-10th of an acre are most convenient, but it is usual to weigh the produce from a representative part of each, 5 or 6 square yards in area. In estimating grain yields there is a difficulty in dealing with such small quantities, as obviously they cannot be dealt with by the ordinary mill, and threshing by flail must be resorted to. An important precaution already mentioned in connection with pot experiments is the multiplication of the plots in order to eliminate the differences due to variations of soil and other accidental causes. No matter how uniform the soil may appear to be this is absolutely necessary if safe conclusions are to be drawn from the experiments, and the following results emphasise the need of this:—(1) As part of the trials made on the College farm in connection with the wheat selection* work conducted by Dr. Hilgendorf, 17 plots were laid out side by side in Field 17, which is one of the most uniform fields on the whole farm. The plots were half-an-acre in extent; all were cultivated, manured, and sown at the same time and in exactly the same way. Alternate plots were sown with a single uniform sample of commercial Hunter's, and the remainder with pure strains. The yields of the separate plots of commercial Hunter's were at the rate of 50 bushels, 51 bushels, 60·5 bushels, 60 bushels, 58 bushels, 56 bushels, 54 bushels, 60 bushels, and 56 bushels per acre respectively, giving an average of 56·2 bushels per acre.

Had these plots been differentially manured one would have been tempted to explain the yields in terms of the fertilisers, so uniform in texture, composition, and other characters did all the plots appear to be before sowing. Yet the variations are due

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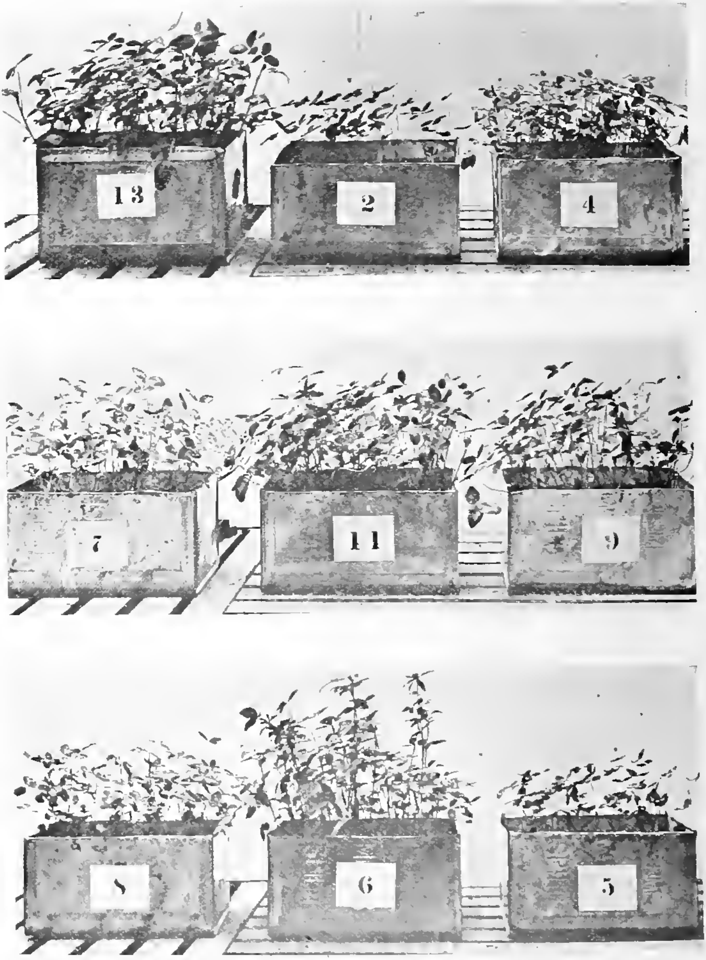
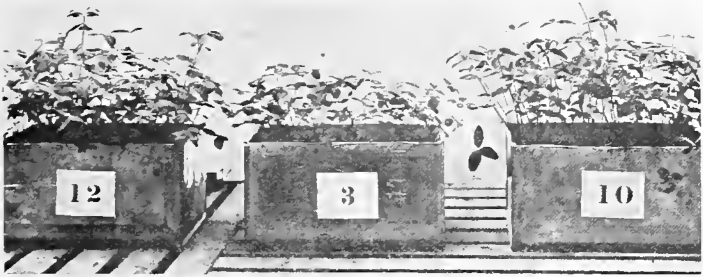
* See Chapter V. contributed to Copland's "Wheat Production in New Zealand" by this writer.



*(By kind permission of N.Z. Dept. of Agric.)*

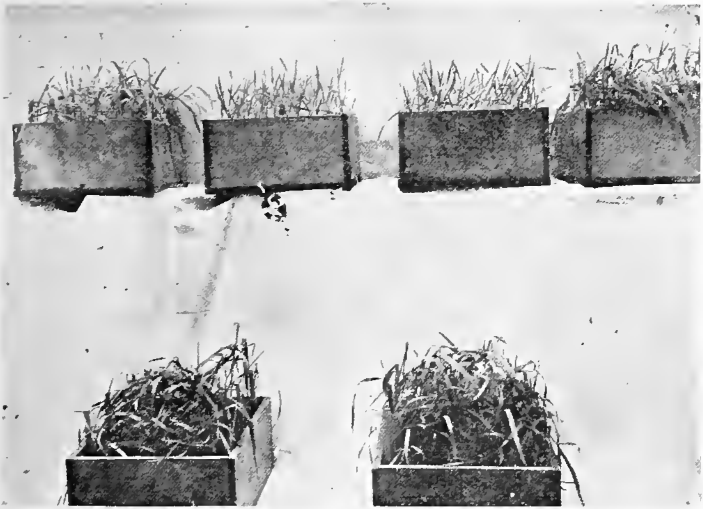
Pot experiments with Pumice Soils, from Mamaku Experimental Farm. Second cutting of clover.
No. 13, dung; 2, limestone; 4 and 7, control (no treatment); 11, rock phosphate; 9, iron oxide; 8, iron sulphate; 6, super; 5, spent iron oxide.



*(By kind permission Dept. of Agric.)*

Pot experiments with Pumice Soils, from Mamaku Experimental Farm
Second cutting of clover.

12, slag and super; 3, limestone; 10, slag.



*(By kind permission Dept. of Agric.)*

Box method of soil-testing.

Soil, Taumarunui pumice loam Top row (left to right) Box (1) 10 tons green manure. (2) no manure. (3) 10 cwt. super. (4) same as (3) with green manure. Bottom row, Box (1) 3 cwt. super., 3 cwt. slag, 3 cwt. blood, 1 cwt. bonemeal. (2) same as (1) with green manure. (All quantities per acre.)

wholly and solely to variations in soil. (2) The following figures from the *Journal of Agriculture* summarise the results of an experiment to determine the most suitable manures for swedes at Ardgowan, in Otago:—

| Plot. | Manures. | Total yield. |
|---|---|---|
| 1. | Superphosphate, 1½ cwt. .. | 23·7 |
| 2. | Superphosphate, 3 cwt. .. | 19·7 |
| 3. | Super 2 cwt., Bonedust ¾ cwt. .. | 39·9 |
| 4. | No manure .. .. .. | 42·4 |
| 5. | Super 2 cwt., Bonedust, ¾cwt. sulphate of potash ¼ cwt. .. | 39·9 |
| 6. | No. 5 mixture, 1½ cwt. .. | 44·5 |
| 7. | No. 6 mixture 1½ cwt., salt 14 lbs. | 42·1 |
| 8. | Albatross guano, 2 cwt. .. | 39·9 |

It is difficult to interpret these results except on the basis of what is called the experimental error. A possible, though not probable, explanation is that manures, especially acid ones such as superphosphate, actually do injure the yield, though why a little bonedust should remove the injurious effect is difficult to see. Another explanation is that the manures were sown so near the seed as to seriously affect its germinative capacity and the well-being of the seedling; but no abnormalities as to germination and so on are mentioned in the report. Certainly the results are more extraordinary than most of those so obtained, and for that reason were probably rejected. But it is just the experiments the results of which appear to be probably true because of their reasonableness that are probably of least value because of the unknown effect of the experimental error.

To avoid the effects of the variations which give rise to the experimental error, multiplication of the plots is the only satisfactory way. They should be at least triplicated, and it should always be remembered that many small plots are better than one big one. The best way to avoid an inconveniently large number of plots is to reduce the number of manurial mixtures to be tried rather than to limit the number of plots of each prescription.

### For Further Reference.

Papers in "The Journal of Agriculture."

G. de S. Baylis—Box Methods of Testing Soils. August, 1915.
" " Box Tests of Typical Soils. October, 1915.
" " What is it Your Soil Lacks? May, 1915.
" " Co-operative Experiments: Hints for Farmers. Dec. 1911.
B. C. Aston—Wire Basket Method of Testing Soils. Bull. 2, Chemistry Division, Dept. of Agriculture.

## CHAPTER VII.

## MANURES.

The following classification of manures is the one most useful under our New Zealand conditions:—
A. Soil Improvers. B. Fertilisers.

For definitions of these terms the reader is referred to page 31.

### A.—SOIL IMPROVERS.

1. **Farmyard Manure.**—In the old days of high-priced corn in Great Britain the farmer there kept live stock mainly for the purpose of producing dung with which to manure the corn land, and such manure was the mainstay of his system of farming. The relative prices of corn and meat have changed, however, to such an extent, and the use of artificial fertilisers has spread so that the production of farmyard manure is nowadays incidental to stock raising rather than the direct object of it. In this country owing partly to our mild climate making it unnecessary, and the extensive holdings making it almost impossible to house stock, and partly to the high price of concentrated foods, of which none are manufactured locally, no systematic attempts are made on any large scale to save animal manure, by far the greater part of which returns directly to the land.

*General Characters.*—Farmyard manure is the solid and liquid excreta of farm animals, together with the straw, moss, or other stable bedding with which it becomes mixed. While it contains all the elements necessary to plant nutrition, its composition and the availability of its constituents depend to a large extent on the kind of animal producing it, the state of decay, and the method of saving and storing it. The constituents of urine are soluble and immediately available; those of the litter and of the undigested solid matter must first pass through various stages of bacterial decomposition, which in general results are not unlike those suffered by the organic matter of the soil. The urea of the urine is rapidly converted into ammonium carbonate, which readily dissociates into free ammonia and carbon dioxide, whereby nitrogen, perhaps the most valuable element in the manure, escapes to the air as ammonia gas. Ammonium compounds are also acted on by the oxygen of the air, whereby nitrogen is set free in gaseous form and lost. Losses by both these methods may be minimised by packing the manure heap and excluding air. Chemical methods, such as the use of gypsum scattered among the manure, have also been suggested for the same purpose. Gypsum interacts with ammonium carbonate, giving carbonate of lime and sulphate of ammonia, two fairly stable compounds. To provide sufficient gypsum for this purpose would, however, be too costly, and the same objection applies to the use of kainit and of superphosphate, both of which re-act with ammonium carbonate, tending to retain the ammonia. As a matter of fact a loss of about 15 per cent. of nitrogen seems inevitable, but the loss may greatly exceed this with careless management.

Besides acting on the urea as just described, bacteria act also upon the proteins of the solid components of the manure, which are broken down into more soluble and attackable compounds, such as amides, and subsequently into ammonium compounds.

Other bacteria act on the straw, which rots, loses its structure, and becomes dark brown humus; some of this, being soluble in alkalis, escapes in the alkaline drainage, which is consequently of a brown colour. In saving farmyard manure, therefore, the drainage must also be prevented from escaping, and this is best secured by having sufficient litter to soak it up. The drainage is valuable, not only on account of the humus, but because it contains all the more soluble and readily available manurial constituents.

*Composition.*—Farmyard manure is a "complete" one, in so far as it contains all the elements of plant food, but its chemical composition varies according to the kind of animal, the quality of the food consumed, the age and condition of the animal, and other circumstances. An animal putting on weight or yielding milk will utilise more of the constituents of its food than will a store animal, and consequently the manure produced by it is not so rich. From what has been said about the decomposition of the manure during storage it is obvious also that its compositon will vary with the length of time and the manner in which it has been saved. The following is a summary of analyses made by Voelcker:—

| | Fresh manure 14 days old | From heap 3½ months old | Well rotted 6 months old |
|---|---|---|---|
| Water ... ... | 66·17 | 69·83 | 75·42 |
| Total nitrogen ... | 0·64 | 0·74 | 0·61 |
| Phosphoric anhydride ($P_2O_5$) | 0·32 | 0·32 | 0·45 |
| Potash ($K_2O$) ... | 0·67 | 1·22 | 0·49 |
| Lime (CaO) ... | 1·19 | 1·34 | 1·78 |
| Magnesia (MgO) ... | 0·15 | 0·05 | 0·14 |

*Manurial Value.*—The most important point has already been mentioned, namely, that this is a complete manure, and also a well-balanced one, though the percentage of phosphoric acid is usually rather low. Not only are all the elements of plant nutrition present, but they exist in compounds of varying degrees of availability, so that it is a lasting manure. This is well illustrated by Rothamsted experiments in which plots, years ago manured heavily with farmyard manure for eight years in succession, and left untreated for the last forty years, have nevertheless continued to give higher returns than the altogether unmanured plots alongside.

For crops such as mangels, requiring large supplies of nitrogen rapidly, it frequently happens that farmyard manure alone does not supply that element in an available form rapidly enough to keep the crop going, and better results may be got by using a soluble nitrogenous fertiliser such as nitrate of soda in conjunction with it.

The physical effects of the manure on the texture and water-holding capacity of soils are also very important. Well rotted stuff is very efficient in binding up light lands and cementing the loose particles into the desirable compound particles, while "long" fresh manure assists in the opposite process of opening up heavy soils, making them more porous to air and water, and more friable.

2. **Green Manures.**—Green manuring consists in ploughing under the whole or part of some green succulent crop, such as mustard, oats, peas, clover, etc. The aim of the process is the general improvement of the soil: physically, by the amelioration of its mechanical condition, which controls the air, water. and temperature conditions; chemically, by the supplies of plant food set free in an available condition from the decaying vegetation; biologically, by

the increased supply of organic food for fungi, bacteria, and other soil organisms.

In choosing a crop for the purpose of green manuring, various conditions must be taken into consideration. On the score of economy, it is best to select one that can be raised quickly and at a time when the soil would not otherwise be occupied. Mustard is pre-eminently suitable as fulfilling these conditions, for it can be sown on the stubble in late autumn and ploughed under, if conditions are favourable for growth, in six weeks from the time of sowing. It is also an excellent choice, in that it yields a great bulk of succulent vegetation which readily decays in the soil, giving rise to humus and maintaining the reserves of organic matter.

From the point of view of soil enrichment, however, deep-rooting crops that will transfer food from the subsoil to the soil proper are better. Among such, clover stands out not only on account of its deep-rooting habit, but because it, in common with other pod-plants, is a collector and fixer of atmospheric nitrogen, the very element which is most expensive to buy in the form of artificial fertilisers. Theoretically, therefore, the ploughing under of a clover crop is an admirable means of soil improvement from every standpoint.

Operations, however, that are excellent theoretically are frequently not capable of application, and there are other aspects of green manuring besides the undoubted advantages mentioned above. For example, the conditions necessary for successful green manuring are often absent; namely, sufficient moisture to germinate the seed and grow the crop rapidly, and to encourage the rapid decay of the plants when ploughed under, without the excess that prevents oxidation and produces sourness and undesirable fermentation processes. In the drier parts of the East Coast districts in both islands the rainfall in summer and autumn is often too low to provide for the growth of a large bulk of succulent material for green-manuring.

Again, as to clovers especially, and to other crops in lesser degree, there are important economical considerations. The question must be met whether it will pay better to green manure with the crop or to feed it off with stock and plough under the residue and the dung produced. In deciding this the large reserves of organic matter in our soils must be borne in mind, and the consequent fact that in many cases green manuring is as yet unnecessary; and further, that what is sound practice in one district may not serve in another where the conditions are different.

In general, however, the following principles will furnish a useful guide:—(1) Green manuring by ploughing in before winter autumn raised crops of mustard, or the second growth of rape, is good practice from all points of view. (2) Green manuring in spring or summer with winter or spring sown crops is risky in districts where the annual rainfall is less than 30 inches, because the loss of moisture by transpiration leaves the soil incapable of raising a spring or summer crop. (3) Many of the advantages sought in green manuring are obtained by ploughing in the stubble or other residue of deep-rooting crops and pasture plants, such as clovers, cocksfoot, etc. This last should be considered in selecting seed mixtures for permanent or temporary pastures, which should, therefore, have relatively higher proportions of deep-rooting plants, of which the following have been found specially suited to New Zealand conditions:—cocksfoot, meadow fescue, birdsfoot trefoil, and red clover. Indeed, the principle of including more deep-rooting grasses and other plants in pasture mixtures is the basis of the Clifton Park system of farming certain rather light hilly land in the North of England, which in texture, climatic conditions, and situation resembles to a considerable extent much of our low hilly sheep country.

There are, however, types of soil that can be brought under cultivation only by the aid of green manuring. Such are the light sandy soils common along the margins of both islands, and typically seen on the west coast of Wellington between the Wanganui River and Cape Egmont. Population in this country is not yet dense enough to force settlers on to such lands requiring so much improvement before they can be farmed profitably. But when they are taken up green manuring will undoubtedly be the first undertaking towards bringing them into a profitable condition, and the first crops used for the purpose will no doubt be the sand-loving lupin.

3. **Lime.**—The advantage of liming was early recognised. At any rate marling or chalking was practised by the early Britons, and in parts of England the custom exists to this day of digging a well down to the chalk, hauling it up, and spreading it on the ground.

Lime has a threefold action on the soil—A. Physical, B. Chemical, C. Biological.

A. *Physical Effect of Lime.*—The property of clay of remaining in suspension in water for days and even for months, and its flocculation by acids and by bicarbonate of lime which presently cause the clay to settle down has already been described on page 13. One of the most important effects of lime in the soil is the production of the soluble bicarbonate that destroys the adhesiveness of clay, whereby the soil is made less sticky, more granular, more porous, and therefore drier and warmer. This action is quite characteristic, and is well seen in wet districts with heavy soils and subsoils such as Southland. In parts of this district, for example, the effect of an application of lime in opening up the soil and letting away excess of water is so great, that the soil warms up much more quickly in the spring, and plants start into vigorous growth a week or even a fortnight earlier than on adjacent unlimed land.

On light soils, on the contrary, lime has some cementing powers, though its effect in this direction is not so great as that of humus.

B. *Chemical Effects of Lime.*—Lime is a plant food in itself, but is required by most plants in only small amounts compared with the soil reserves; so that, except perhaps in the case of pod-plants, the importance of dressings of lime for the sake of plant food is negligible. Indirectly, however, lime is of importance from the point of view of nutrition, for by interaction with certain insoluble mineral constituents, *e.g.,* potash and aluminium silicates, it sets free potash from them in a soluble form. It is a case of lime going out of solution into an insoluble form while potash follows the reverse process, and it may be represented by the following statement:—Lime + insoluble potash and aluminium silicates = Potash and lime and aluminium silicates.

Thus the action of lime in encouraging clovers, etc., is in part due to its setting free potash, a constituent required in considerable amount by such plants. The effect of lime in bringing into solution plant food that has hitherto been unavailable forces along the first few crops after its application, but tends to lead to subsequent exhaustion; hence the old "saw":

Lime and lime without manure
Makes both farm and farmer poor.

As lime is a base its application has a very important effect in counteracting the acidity produced by such manures as superphosphate and sulphate of ammonia, which are either acid themselves or tend to produce acid conditions in the soil, and thereby to remove the lime already present.

C. *Biological Effects of Lime.*—Some base is necessary in the soil to neutralise the acids formed by the bacterial process of nitrification, and the cheapest base is lime. A neutral or alkaline soil reaction is also important to keep land free of the fungus that gives rise to "club-root"* or "finger-and-toe" in swedes and other cruciferous crops,—an organism that cannot tolerate any but acid conditions. There are also certain weeds and other plants that in Great Britain are called "calcifuges," from the fact that they will not tolerate lime in the soil. Among such are sorrel, yarr or spurry, and gorse; but in this country other conditions seem to be more active in controlling the distribution of these plants. Sorrel occurs in all classes of soils, but is most difficult to keep under in light land. It is said, however, that this weed has practically disappeared from the Tokomairiro Plain and from the Edendale district since lime has been extensively used there. Rushes, bent grasses, and Yorkshire fog give way before liming provided the drainage is not at fault, and the presence of this type of vegetation, together with the absence of clovers, is the surest botanical evidence of sour conditions.

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* See pages 18 and 38.

The "depraved taste"* for bones, etc., often exhibited by stock, especially by cows, is considered to be evidence of something lacking, probably lime or phosphate, in their feed. How far this may be the true explanation, and how far liming will go to correct the trouble, it is not at present possible to say.

*Forms in which Lime is Used.*—Lime occurs abundantly in nature, but more especially in limestone, marble, and chalk. When pure these rocks are composed of carbonate of lime, which though insoluble in pure water, dissolves readily in weak acids, including carbonic acid or water containing dissolved carbon dioxide. With this it forms bicarbonate of lime, which is soluble in water. Deposits of limestone are widely distributed throughout New Zealand, as in North Auckland, in the King Country, in Hawke's Bay, in the Wairarapa, in South Marlborough, in North and South Canterbury, in North and South Otago, and in Southland, and in most of these localities the deposits are worked. Limestone is never quite pure, but contains more or less sand, some iron, and sometimes phosphatic material. Chalk is a soft form, sometimes soft enough to be applied direct to the land without grinding. Marl is a very impure rock containing much clay and sand with varying amounts of carbonate of lime.

When limestone is burnt in a kiln several important changes take place. The heavy inert rock is converted into a light porous rock, which has a characteristic feel and gives a sort of clinking sound when rubbed with the fingers. It is now called burnt lime or quick lime. In chemical terms, the carbonate of lime has lost carbonic acid and become oxide of lime, the substance to which the use of the term "lime" should be confined.

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* See page 22.

It was formerly the custom to use lime in the lump form just as it comes from the kilns—rock, roche, or shell lime as it is called. It was stacked in the field in heaps at suitable intervals apart, and after being allowed to "slack," a process to be described presently, it was broadcasted. It is usual nowadays to grind the lime and distribute it by means of a suitable distributing implement.

When burnt lime is exposed to the atmosphere it gradually absorbs moisture with which it combines very readily, giving out heat, swelling up, and crumbling to a very fine powder. This is "slaked" or "slacked" lime.

Both quick lime and slaked lime also absorb carbon dioxide from the atmosphere whereby they are reconverted into carbonate of lime.

The ultimate fate of all forms of lime in the soil is conversion into bicarbonate of lime, a soluble compound readily washed into the subsoil. This is the reason that dressings of lime have to be repeated from time to time.

*Relative Advantages of Lime and Carbonate of Lime.*—Which is best, lime or carbonate of lime, is a question very frequently asked. Before attempting an answer let us compare the properties of the two substances. Lime usually gives quicker results than the carbonate because it becomes distributed more evenly and more quickly. This, again, is because lime on slaking falls to an exceedingly fine powder that is either carried into the soil mechanically, or that, being soluble, is distributed in solution. On the other hand the solution of lime in water is able to dissolve humus, so that organic matter tends to some extent to be removed from the soil. The quantity so removed is, however, not great, and is in fact negligible in soils tolerably well supplied with organic matter.

The flocculating or granulating of the clay particles of a soil, by which its texture is improved, is the work of the bicarbonate form of lime, and the rapidity with which the effect will be noticed depends on the efficiency of the distribution in the soil and the rate of conversion into bicarbonate. In this respect burnt lime has the advantage.

It has recently been shown that burnt lime, but not carbonate of lime, has an important effect on the soil micro-organisms, the net result being increased bacterial activity and consequently increased production of nitrates. Burnt lime also brings about a decomposition of the nitrogenous organic constituents of the soil, whereby the food supply both for bacteria and for plants is increased.

From theoretical considerations lime should be best on heavy soils with much clay, and sufficiently supplied with organic matter, while carbonate should serve best on light lands. Unfortunately there have been no sets of experiments in New Zealand designed to settle this question, and while outside experience is useful and interesting it cannot be accepted as a certain guide. Experiments conducted over a considerable period in England and in different States of America have shown that in the long run limestone is better than lime. With us, however, there are certain points on the score of economy and convenience that will usually be the basis of decision. In the first place, limestone loses weight when it is burnt, useless carbon dioxide being got rid of, so that one ton of burnt lime is as useful for soil improvement as about 1¾ tons of carbonate of lime. To compete with burnt lime, therefore, carbonate should be correspondingly cheaper, roughly about seven-twelfths of its price. Burnt lime being 24/- the ton, carbonate should be not more than 14/-. Where cartage is a big item, burnt lime, being the more concentrated form, again has the advantage. On the other hand, burnt lime cannot be left long in bags; it absorbs moisture, swells, bursts the bags, generates heat, and is a menace to property. Carbonate of lime can be kept in bags indefinitely. Lime. again, has a caustic or burning effect on eyes, nose. and throat of man and beast that makes it a very objectionable material to handle.

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## B.—FERTILISERS.

In New Zealand two distinct classes of fertilisers are employed: A. Single fertilisers, such as nitrate of soda, superphosphate, and kainit, which supply one single element of plant food; B. Compound fertilisers, which are more or less "complete" in that they contain at least two, and sometimes all three, of the essential elements of plant nutrition. Chief among such are the mixtures supplied by freezing works and manure merchants; guano; and bonedust. For descriptive purposes it will be convenient to sub-divide the group of single fertilisers according to the constituent that each is intended to provide; thus, we shall introduce three kinds: phosphatic fertilisers, nitrogenous fertilisers, and potash fertilisers.

## Phosphatic Fertilisers.

1. *Rock phosphate* occurs in many parts of the world. It is sometimes merely ground finely and used raw, as in America, or it is made into superphosphate of lime. Some of it is of mineral origin, as that of Spain and of Canada; other deposits are really guanos from which the nitrogenous matter has been leached by rain, as *e.g.*, those of the islands of the Pacific Ocean.

The importation of phosphates into this country has shown a steady annual increase, and amounted for the year ending March 31st. 1915,* to 117,849 tons, valued at £421,181. As the demand must continue it will be useful to consider our sources of supply.

(*a*) New Zealand Deposits.—Mineral phosphate in workable quantities has so far been discovered only at Clarendon and at Milburn, in South Otago. Here it consists of earthy mineral apatite found as beds 10 or 12 feet thick resting in pockets in the limestone of that district. It is considered by Dr. Andrew to be derived from the bones of animals which have been dissolved and the phosphate re-deposited. The rock is yellowish-white, or light grey in colour, and contains about 60 per cent of tricalcic phosphate. After quarrying it is graded, dried to expel moisture by placing on heaps of wood which are set on fire, and ground to a fine powder, and either used in this con-

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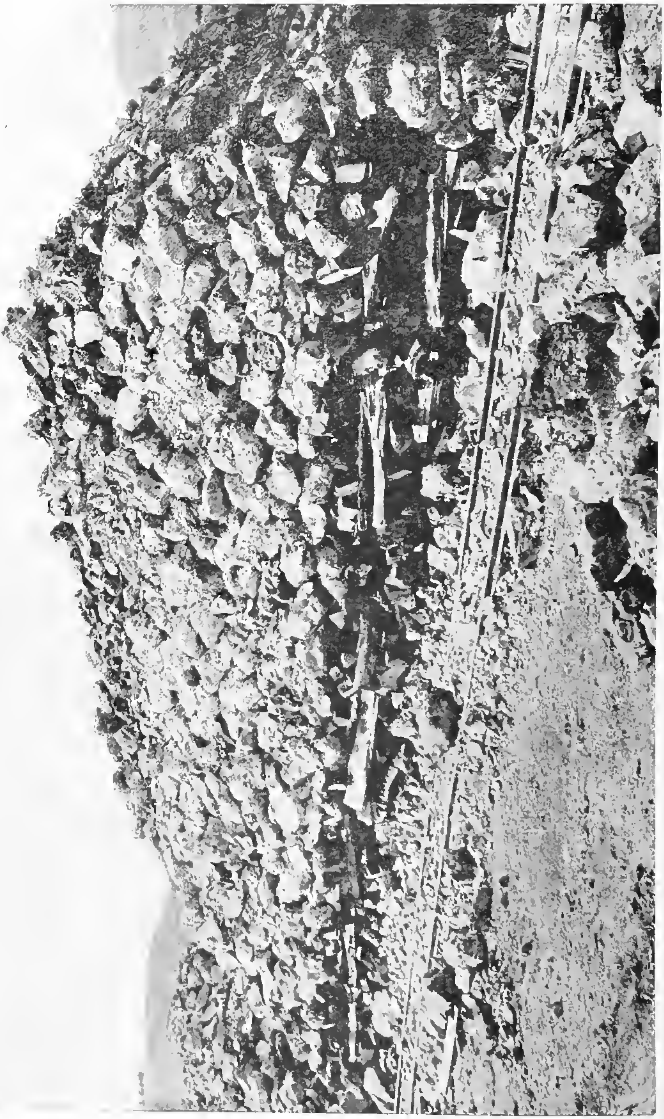
* Since 1915 there has been a slight increase owing to war conditions.



Heap of rock phosphate at Clarendon, Otago, ready for burning.

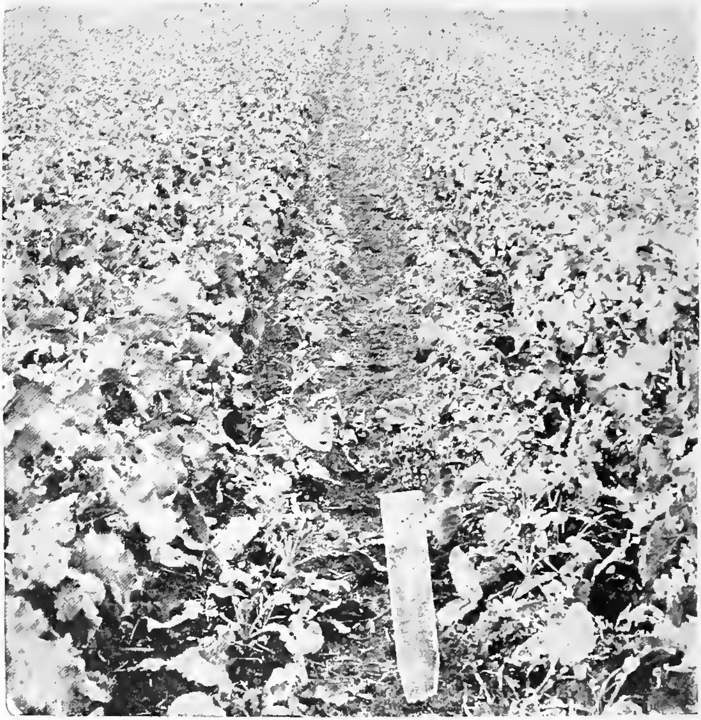
*(By kind permission of N.Z. Dept of Agric.)*

dition or made into superphosphate. The output at present is about 10,000 tons per annum.

At Weka Pass, in North Canterbury, there are to be found nodules containing 36 per cent. or so of tricalcic phosphate; and many specimens, some of them richly phosphatic, have been obtained at Whangarei, though the mass from which they have been derived has not yet been found. The facts that the discovery of the Otago field was the result of a systematic search and that the price of phosphate in New Zealand is high enough to guarantee a fortune to the discoverer of a workable deposit, should encourage search in the districts named, as well as in other localities where limestones and greensands occur, as, for example, in Southland, in North Otago, near Waimate, in the Weka Pass and Cheviot districts, in South Marlborough, and in North Auckland.

(*b*) Islands of the Pacific Ocean.—The material from these sources is guano, from which all nitrogen has been removed by natural processes, so that it is now more mineral than animal in appearance and general characters. Some of it is of very high grade, containing over 80 per cent. of tricalcic phosphate, a large proportion being readily soluble in weak acids such as citric acid, and therefore, by inference, in the soil. Among the chief islands from which supplies reach this country are Ocean Island, Nauru, Malden, Makatea, Surprise, Chesterfield, etc. Some of the stuff is made into superphosphate at Burnside along with the Clarendon rock, while the rest is simply ground finely and used in this condition. The superphosphate made at Mt. Lyell, in Tasmania, and in some other parts of Australia, is also mostly made out of phosphates from these islands.

(*c*) A deposit of great importance to New Zealand is that at Safaga Bay, in Egypt, near the Red Sea, from which a regular supply should be obtainable in normal times. This material, known in New Zealand as Ephos phosphate, is a high grade phosphate,



*(By kind permission of N.Z. Dept. of Agric.)*

Effect of Phosphates on Swede Turnips. Two rows in centre received Potash and Nitrogen, but no Phosphate. Yield 1¾ ton. Rows on either side received Phosphates only. Yield 30 tons.
(See also illustration on page 61).

containing about 16 per cent. of free carbonate of lime, in addition to over 60 per cent, of tricalcic phosphate, over 90 per cent. of which is soluble in a very weak (0·2 per cent.) solution of citric acid.

Reduction to a fine powder, after drying, is all that is required to render this material fit for immediate application.

(*d*) Other Islands.—Supplies of phosphate of variable quality reach us at irregular intervals from islands such as Christmas Island in the Straits Settlement (60 to 80 per cent.) ; Seychelles Islands (40 to 60 per cent.) ; Abrolhos; Madagascar.

2. *Superphosphate* is made by the action of sulphuric acid on raw mineral phosphates, whereby a phosphatic compound that is soluble in water is produced. Such material contains about 14 to 18 per cent. of phosphoric anhydride in soluble form and usually 2 to 3 per cent. in insoluble combinations.

As a fertiliser for all crops superphosphate has obtained great popularity in this country, and especially so for turnips in the drier districts. It is the only manure containing water soluble phosphate, and therefore gives a very quick response. There can be little doubt that it pushes crops ahead through the early stages of growth, giving them the initial vigour necessary to enable them to forage for themselves later on in life. It seems to exercise a stimulating effect on root growth especially; indeed it is to this effect that Sir A. D. Hall attributes its successful application in wheat-growing in Australia. There is a popular idea that superphosphate, because it is water soluble and quick acting, does not remain in the soil but is washed out unless immediately taken up by plants. This is quite wrong; indeed it has been shown that "super" lasts in the soil equally as well as the insoluble basic slag.

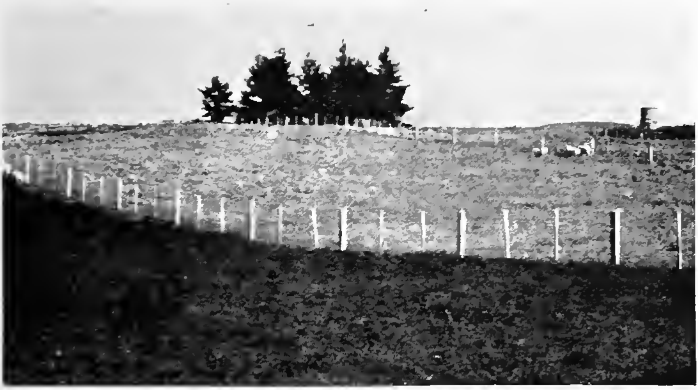
3. *Basic Superphosphate.*—The objection to superphosphate that it is an acid manure has been overcome by mixing with it about 15 per cent. of slaked lime,

whereby a material of basic reaction is produced. This is "basic super." An important difference from superphosphate, besides its basic reaction, is the fact that it contains no water soluble phosphate.

But "basic super," though insoluble in pure water, is quite readily soluble in weak acids, and therefore in the soil water, and is almost as quick acting as "super." On many soils it has all the advantages of "super" without any of its disadvantages. It is usually in better mechanical condition than "super," remaining drier and more friable after storage. On soils of an acid nature, such as those of the Canterbury Plains, the Wairarapa, the Manawatu, and the Waikato it should always be used in preference to "super," unless separate dressings of lime have been made. It must be remembered, however, that basic superphosphate is less rich in phosphoric anhydride than "super," containing about 12 per cent.

4. *Basic Slag* (*Basic Cinder, or Thomas Phosphate*).—This is a waste product from the manufacture of steel. It is a fine, heavy, dark-brown or black powder, containing on an average about 15 per cent. of phosphoric anhydride, equivalent to 33 per cent. of tricalcic phosphate, together with free lime, magnesia, iron, iron oxide, and silica. Much of the phosphate is readily soluble in weak acids, such as carbonic acid and citric acid, and, therefore, in the soil water; indeed it is considered to be more rapidly available to the plant than mineral phosphates.

Basic slag is an excellent phosphatic manure for the heavier types of soils, especially where the supply of moisture is good. It is especially popular in the Auckland province, and the North Island generally, where for top-dressing and renovating pastures it gives phenomenal results, improving both the quantity and quality of the herbage. It should give equally good results in the wetter districts of the South Island, where, indeed, its popularity is increasing. Its efficiency as a manure is dependent to a considerable extent on its degree of fineness, and the buyer, in addition to noting the percentage of phosphoric anhydride and the degree of solubility, should insist on a sample not less than 80 per cent. of which will pass through a sieve having 100 wires to the linear inch.



*(By kind permission of N.Z. Dept. of Agric.)*

The field in the foreground was top-dressed with basic slag. The field over the fence received no manurial treatment.

## Potash Fertilisers.

The ashes of wood and of seaweed, which contain potassium carbonate or "potashes." were the only supply of potassium compounds open to agriculturists until the opening up of the Stassfurt deposits of Germany, about 1860. As these deposits are, by reason of conflict with Germany, at least temporarily closed to us, it will be well to consider first the actual and potential local sources of these expensive manures.

1. *Wood Ashes.*—Wood yields from 0·3 to 3 per cent. of ash, the composition of which varies considerably with the age and the kind of timber. The completely burnt ash contains from 2 to 20 per cent. of carbonate of potash, 10 to 30 per cent. of lime, 1 to as much as 18 per cent. of phosphate of lime, with smaller quantities of other constituents of little or no importance from the present point of view. The manurial value of wood ashes has long been known and well appreciated. As a fertiliser the fresh ashes should be used, without any preliminary treatment, such as extraction with water to obtain the potash salts in more concentrated form, for not only would carbonate of potash have a harmful effect on soil texture, but the lime and phosphate have a positive value.

Wood ashes, however, do not ordinarily come on the market for they are produced in quantity only at out-of-the-way places such as bush sawmills, whence transport is expensive. That there is an opportunity for the creation of an industry is shown, however, from Aston's analyses and calculations printed in the *N.Z. Journal of Agriculture* for October, 1915, some of which are appended. The values in this table are derived from the following fertiliser unit values:—Potash, 9/- per unit; phosphoric anhydride, 2/6 per unit; lime, 4d. per unit.

## ANALYSES AND VALUES OF WOOD-ASHES.

### B. C. ASTON.

| NAME OF WOOD | Loss on Ignition, Carbon, etc. | Analysis of completely burnt ash | | | Approximate Value per ton | |
|---|---|---|---|---|---|---|
| | | Potash ($K_2O$) | Phosphoric Anhydride ($P_2O_5$) | Lime (CaO) | Sample as Received | Completely Burnt Ash |
| Rimu (red pine) .. | 7·96 | 3·10 | 0·88 | 37·68 | £1 19 6 | £2 3 0 |
| Macrocarpa .. (Cupressus macrocarpa) | 12·62 | 6·84 | 2·25 | 35·97 | £3 9 0 | £3 19 0 |
| Manuka .. (Leptospermum sp.) | 7·41 | 2·38 | 3·40 | 33·32 | £1 18 0 | £2 1 0 |
| Rata .. .. (Metrosideros sp.) | 5·16 | 8·28 | 1·63 | 20·58 | £4 1 0 | £4 5 6 |
| Sawmill Ash .. | 7·89 | 5·88 | 1·13 | 17·09 | £2 17 0 | £3 2 0 |
| Totara and Rimu .. (Podocarpus totara and Dacrydium cupressinum) | 4·72 | 14·37 | 1·68 | 34·61 | £6 18 0 | £7 5 0 |
| Monterey Pine .. (Pinus insignis) | 28·32 | 0·12 | 2·57 | 10·05 | £0 7 6 | £0 10 6 |
| Macrocarpa cuttings (Cupressus macrocarpa) | 8.79 | 6·96 | 2·64 | 26·14 | £3 11 0 | £3 18 0 |

Farm rubbish is, as a rule, better ploughed in direct or collected into a compost heap to rot than burned for burning not only liberates the nitrogen, but it destroys the valuable humus-forming organic matter Hedge-trimmings are often too bulky to plough in, while it is inconvenient to burn them and collect the ash. The ash of the clippings of the gorse hedges, so common in many parts of the country, is worth as much as £12 12s. per ton compared with the prices of ordinary potash manures.

2. *Unwashed Wool.*—This contains 5½ per cent. of potash, most of which is removed in washing. By far the greater portion of our wool is exported in the

greasy state, however, whereby we lose this supply, as well as the valuable wool-grease and lanoline.

3. *Rocks and Minerals.*—Many rocks and minerals common in this country contain considerable amounts of potash, which, however, is locked up in rather "unavailable" compounds. Potash mica and potash feldspar yield from 11 to 14 per cent. The mica schists occurring widely in Otago and Westland contain 3 per cent.; glauconite, the characteristic mineral of the Greensands formation, contains 8.12 per cent.; the greensands themselves contain 3 per cent.; while at Dunedin there is a considerable variety of alkaline rocks containing from 4 to 7 per cent. of potash. No practicable methods have been discovered, however, for extracting the potash from rocks. A product known as Wiborgh phosphate,* made by fusing phosphatic and potash minerals with carbonate of soda is said to contain the potash in a fairly available form, but the material is looked upon rather as a phosphatic fertiliser.

4. *Flue-dusts* from various factories and cement works are also likely to yield considerable amounts of potash in the near future.

*The Stassfurt Deposits of Germany.*—Stassfurt is near the Hartz Mountains, and the deposits are the result of the drying up in a hot climate of a great lake or sea which retained some connection with the ocean so as to admit of a constant inflow of more water. In digging down into the deposits one first passes through a layer of red sandstone and limestone about 600ft. to 800ft. thick, beneath which are beds of gypsum and of rock salt, for which the deposits were first exploited. Underneath this is a layer of salt clay, forming a waterproof protection to the potash salts below. These are naturally divided into three great bands or regions:—

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*See page 113.

1. The Carnallite Region, 50 to 130ft. in depth, containing chiefly chlorides of potash and magnesia, and constituting the principal source of the manufactured materials.
2. The Kieserite Region, containing mainly crude sulphate of magnesia.
3. The Polyhalite Region, where the principal salt is a complex sulphate of potassium, lime, and magnesium.

Below this is the older bed of rock salt, over 2000ft. thick, interspersed with layers of anhydrous sulphate of lime, and underneath all is the floor of sandstone.

From these deposits many potash salts are produced.

The chief products coming before the agriculturist are as follows:—

1. Muriate of potash or chloride of potash, containing about 82 per cent. of the pure salt, equivalent to 52 per cent. of potash.

2. Sulphate of potash, which usually contains about 93 per cent. pure salt, that is, 50 per cent. potash.

3. Kainit, containing the equivalent of 11 to 12 per cent. of potash.

4. "Potash manures," made by grinding up mixtures of the raw materials, and containing varying equivalents, frequently about 30 per cent. of potash.

These materials are usually white, grey, or pink granular substances, very soluble in water, and usually very deliquescent.

*Use in New Zealand.*—The crops for which potash fertilisers are mainly required in New Zealand are mangels and potatoes. For mangels kainit is the best, on account of the common salt it contains; while for potatoes sulphate of potash is considered most suitable. Muriate of potash is said to make potatoes waxy, an effect ascribed to the chlorine assisting the migration of starch about the plant.

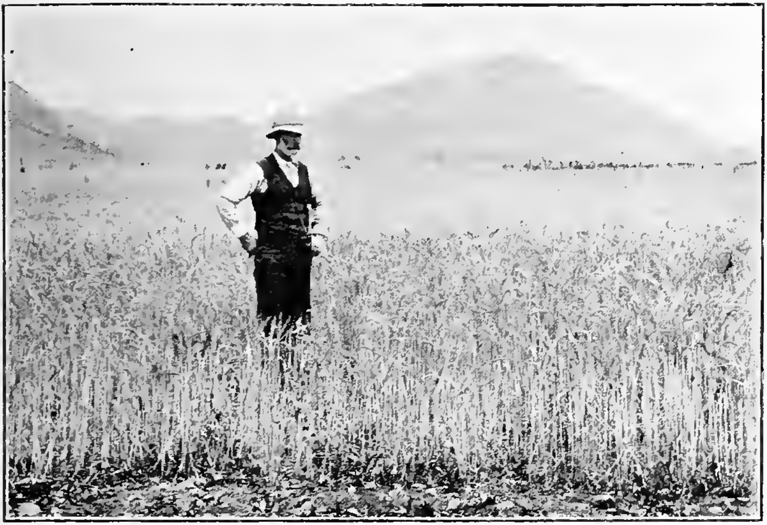
*Other External Sources of Potash.*—Deposits of potash minerals have also been discovered in Alsace and in Spain, but they have not yet been opened up, at any rate for export. In America a fair amount of potash is being obtained from seaweed. In the same country deposits of the potash-bearing mineral alunite are also yielding a fair supply, and the same will perhaps soon be said of similar deposits in Australia.

## Nitrogenous Fertilisers.

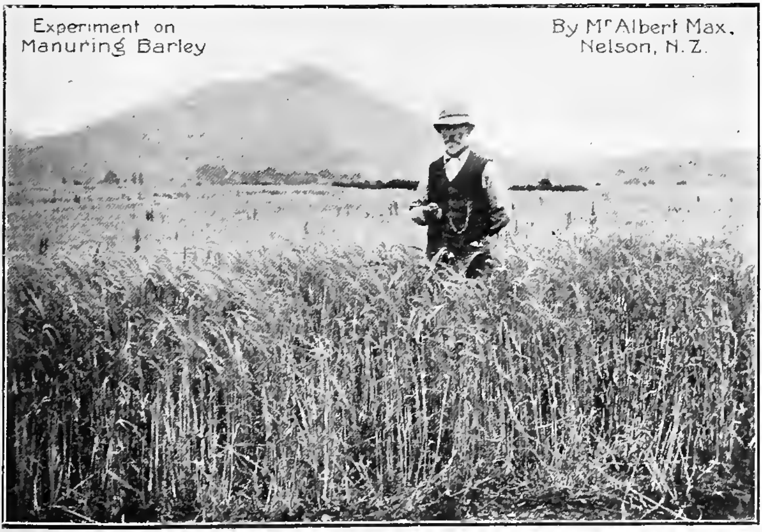
1. *Nitrate of Soda, Chile Saltpetre.*—Nitrate of soda is a white, grey, or yellow granular salt prepared from deposits of the crude material found in Chile. It is very soluble in water, absorbing moisture readily from the air, and is poisonous if taken by stock in quantity. It is not in any way retained in the soil, and is therefore liable to loss by drainage, and should be applied to the young growing crop, so as to be absorbed immediately. On account of this circumstance it is much used with shallow-rooted crops such as barley, the roots of which tend to follow the disappearing nitrate into the subsoil. It may be mixed with other manures except superphosphate and dissolved bones, the free acid in which gradually liberates nitric acid whereby nitrogen is lost; these manures may, however, be mixed immediately before application.

The salt is usually about 96 per cent. pure, and therefore contains 15·7 per cent. of nitrogen. The

# EXPERIMENT IN MANURING BARLEY.



Plot 1. Grain Manure, 1 cwt. per acre. Yield 25 bushels per acre.



Plot 2. Grain Manure, 1 cwt. per acre, plus nitrate of soda, 70 lbs per

soda is also useful, not because soda is essential to plant nutrition, but because it reacts with the potash compounds in the soil, setting free soluble potash, and going into combination itself. Thus at Rothamsted plants manured with a soda salt have in twenty years absorbed 263 lbs. more potash than those not so treated.

Nitrate of soda* has a harmful effect on soil texture and tilth. This is because plants remove the nitrate portion but leave most of the soda, which combines with carbonic acid to form carbonate of soda, which has a deflocculating effect on the clay particles, increasing their stickiness. On the Rothamsted plots that have been manured successively with alkaline manures such as this, the tilth is completely destroyed, and the crop fails except in very favourable years. This bad texture is not easily removed; it is best to avoid it by applying with the nitrate of soda an acid manure such as "super," or one such as sulphate of ammonia (q.v.) which gives rise to acid conditions in the soil.

As a fertiliser the value of nitrate of soda is its immediate availability, on account of which it is used as a top-dressing for pastures, and to push forward crops at critical stages. Reference has already been made (see page 42), to the almost universal use of nitrate of soda at Home as a top-dressing to wheat in the early spring. It is also useful to push forward turnips, rape, etc., when aphis or fly threaten the young crop. Except when used with other mineral fertilisers, however, it is said to exhaust the soil of available phosphates and potash owing to the vigorous growth encouraged by a plentiful supply of nitrates.

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*See page 13.

It cannot be said that nitrate of soda is yet used to any great extent in New Zealand; indeed, it is only during the last five years, since the Chilean Nitrate Propaganda started operations, that serious attention has been paid to its use. There is reason to believe, however, that in certain districts at all events, this particular fertiliser, which has been used for many years very extensively in the Northern hemisphere, is capable of producing very considerable increases in crop yields.

The crops which have been shown to respond most to nitrate of soda are fruit, grass, mangels, and carrots, and particularly crops, including vegetables, of the leafy kinds. Oats, wheat, and barley have in experiments all responded to spring top-dressings, as also rape, and even legumes. The price has always somewhat prejudiced agriculturists against the use of any of the concentrated nitrogenous fertilisers, but no doubt an increased demand will in time secure more regular and cheaper supplies.

For mixed "proprietary" manures sulphate of ammonia is usually preferred, as it mixes better with superphosphate. It is as a top-dressing that nitrate of soda has always held a leading place with farmers of the Old World.

2. *Ammonium sulphate.*—The chief source of this fertiliser is the "ammoniacal liquor" of the gas works. Coal contains 1½ to 2 per cent. of nitrogen; when used for gas making about 15 per cent. is given off as ammonia, which is absorbed by the water used to wash the gas. This "ammoniacal liquor" is the distilled with milk of lime, the ammonia is absorbed by sulphuric acid, and the sulphate crystallizes out.

The product is also recovered from blast furnaces, shale works, etc.

The commercial sample is crystalline, and varies in colour, white, gray, yellow, even pink. It is generally about 95 per cent. pure, and hence contains 20 per cent. of nitrogen. Thus weight for weight it is richer than nitrate of soda.

Sulphate of ammonia is soluble and wholly volatile. The farmer, therefore, has two easy tests of purity at hand: any part that does not readily dissolve in cold water is impurity; and any residue left after heating a handful at low red heat on a shovel is foreign matter. An occasional impurity is ammonium sulpho-cyanide, a plant poison. Ammonium sulphate reacts with alkalis, such as caustic soda and lime, whereby ammonia is set free, and therefore should not be mixed with lime or basic slag or basic "super."

Nitrogen for nitrogen, sulphate of ammonia is as effective as nitrate of soda, and is nearly as active; the old idea that it must be converted into nitrate by soil bacteria before plants can use it has recently been shown to be erroneous in the case of a great number of farm plants. It has the advantage that it does not suffer loss in the drainage water, the ammonium portion of the salt being absorbed by the soil.

When sulphate of ammonia is put on the soil, part of it is always oxidised by bacteria into nitric acid, which enters into combination with lime to form calcium nitrate. Moreover both plants and micro-organisms absorb more of the ammonium part than they do of the sulphate, which remains behind as sulphuric acid or combines with lime to form calcium sulphate. Thus sulphate of ammonia tends to create acid conditions in the soil by the liberation of sulphuric acid, by the formation of nitric acid, and by the removal of the base lime by both of these.

3. *Calcium nitrate, Air Saltpetre; Norwegian Saltpetre; Nitrate of Lime.*—Nitrogen, though

a very inert element, may be made to combine with oxygen at the temperature of the electric arc. The oxides so formed dissolve in water, giving nitric and nitrous acids, from the former of which nitrate of lime is prepared.

Nitrate of lime has proved in Europe to be a very useful fertiliser. Judged on a basis of equal quantities of nitrogen it is considered to be as good as nitrate of soda. The lime it contains remains behind as carbonate of lime, and so tends to improve the soil texture. It has the serious objection of readily absorbing moisture from the air. Little of it has yet been used in this country, but where a nitrogenous fertiliser is necessary it should suit our conditions almost better than any other.

4. *Calcium Cyanamide, Nitrolim.*—Nitrogen can be made at high temperatures to combine with some metals and allied bodies to form substances which under the action of water yield ammonia. Calcium cyanamide is manufactured by passing nitrogen over ground calcium carbide heated in iron tubes. The calcium carbide is made by heating a mixture of chalk and coke in the electric furnace; the nitrogen is prepared by passing air over red-hot copper or by the fractional distillation of liquid air. Factories are in operation in Italy, Norway, Germany, and America, an essential condition being cheap water power.

Nitrolim (nitro-lime) is a fine dark-grey or black powder, rather difficult to sow on account of its light powdery nature. It contains about 20 per cent. of free lime, and therefore readily absorbs moisture and cakes, and there is liability to loss of ammonia by decomposition. Treatment with just sufficient steam to slake the lime renders it granular and easier to handle, and it is in this form that it is now placed on the market. In the soil it reacts with water, yielding ammonia and calcium carbonate, a change that is encouraged by bacteria.

It was at first supposed that if the nitrolim were sown with the seed the ammonia thus produced would seriously affect the germination, but later results show that this fear is groundless unless the fertiliser is used in excess. Calcium cyanamide, if pure, contains 35 per cent. of nitrogen; the commercial nitrolim contains about 20 per cent., roughly the same proportion as ammonium sulphate. Weight for weight, however, it is scarcely so satisfactory as the latter.

5. *Waste Products.*—In Great Britain the residues from slaughter-houses, fish-curing sheds, works dealing with wool, skins, etc., all of which contain nitrogen, and some of them phosphoric anhydride, are used locally as nitrogenous manures. In New Zealand the chief product of this kind is the offal of the freezing works. This is worked up into compound mixtures, which are dealt with in the next chapter. A few other substances of use as nitrogenous fertilisers, but produced on too small a scale in this country to come on the market in farmers' quantities are dealt with in Chapter VIII. Among such are soot, shoddy, etc.

### Compound Fertilisers.

1. *Bone Products.*—Bone consists of a mineral framework of carbonate and phosphate of lime, permeated by fat and cartilage containing nitrogen. Bones had been used as manure for ages in the raw condition, but as early as the 17th century it began to be realised that crushing would render them more soluble in the soil, and material ground to about the size of a marble came to be used. Later on they were placed on the market as "quarter-inch bone,"

having been ground to pass a ¼-inch mesh; but nowadays with "quick returns" as the watchword it is customary to reduce them to the coarse powder, bone dust. Such material contains 3½ to 4½ per cent. of nitrogen and about 22 per cent. of phosphoric anhydride, *i.e.*, 48 per cent. of tricalcic phosphate. It thus supplies two essential elements of plant growth, namely phosphorus and nitrogen.

But as well as being used in the natural state, bones are sometimes submitted to other treatment. Dissolved bones, made by treating the crushed material with enough sulphuric acid to render about one-third of the phosphate water-soluble, have been used since the early part of last century. The chemistry of this process is similar to that of the manufacture of superphosphate (q.v.). Dissolved bones contain 1½ to 3½ per cent. of nitrogen, 4 to 8 per cent. of water-soluble and 8 to 12 per cent. of insoluble phosphoric anhydride.

Steamed bone meal is bone dust that has been treated with steam at high pressure, whereby the fat is melted and removed, together with some of the nitrogenous material. This product contains about 1 per cent. of nitrogen and about 22 per cent. of phosphoric anhydride.

Little bone dust is manufactured in New Zealand, by far the greater part of the bone available at freezing works being converted into blood-and-bone mixtures in a manner to be described later on. The little that is turned out is derived mainly from the clean bones gathered by casual collectors. Most of our supplies come from Sydney or Calcutta. There is little doubt that the traditional popularity of bone dust has not been justified in this country, and that the price usually charged is much above its real agricultural value. Of course it must be remembered that bone dust is an approach to a "complete" fertiliser, since it contains two essential constituents, phosphoric anhydride and nitrogen, both of them in forms that become available to the plant only gradually. These advantages, however, do not appeal to us much in this country, where nitrogenous manures if wanted at all are required in an immediately available condition; and where superphosphate and basic slag, containing cheaper phosphatic units, give more immediate, greater, and probably as lasting effects. That popular opinion inclines in this direction is evident from the annual importations of fertilisers for the last half-dozen years before the war, which show a gradual decrease in the amounts of bone dust and a rapid increase in basic slag.

2. *Guanos.*—Guano proper consists of the excreta of sea-birds, together with carcases of dead ones, feathers, scraps of fish, seaweed, etc., which have accumulated on ocean islands frequented during the breeding season, and which have become dried and preserved by the intense heat and the dryness of the atmosphere, which prevents fermentation to a large extent. Fish being the sole diet of the birds, the material is very rich, containing when fresh about 18 per cent. of nitrogen and 9 per cent. of phosphoric anhydride. As the deposits get older a certain amount of change goes on, some of the nitrogenous material being converted by fermentation into ammonium carbonate. Of this, some is lost by volatilisation, some is dissolved out along with the more soluble phosphates and potash by the occasional rains. Thus the older a deposit is the less nitrogen it has and the higher its percentage of insoluble phosphate.

The original Peruvian guano came from groups of islands off the coast of Peru, export from which began about 1840. The output is now limited, and none is available in New Zealand.

Peruvian guano is a loose, dry, grey or brown powder. It is easily sown, and its special manurial value is that it is well-balanced, rich in phosphate as well as in nitrogen, and containing also some potash. Moreover, the compounds containing these constituents are varied in nature, differing in solubility so that a steady supply becomes available throughout the whole growing season.

The so-called guanos that come to us from some of the islands of the Pacific Ocean and elsewhere are not true guanos, since the nitrogenous matter has been removed from them by the action of rain water. They are now wholly phosphatic fertilisers, and have already been dealt with in this connection. Malden Island guano contains from 40 to 55 per cent. of tricalcic phosphate, and that from Seychelles Island about 60 per cent. Ground finely they give very good results in districts of good rainfall.

3. *Wiborgh phosphate* is a German preparation made by fusing rock phosphate, potash feldspar, and crude carbonate of soda. It contains about 27 per cent. of phosphoric anhydride and about 1·5 per cent. of potash. It has not been used in New Zealand.

4. *Freezing Works Manures.* The frozen meat industry is the source of an enormous quantity of offal, all of which is utilised. At a big works in full-swing, sheep are killed at the rate of several thousands a day. The blood drains away into reservoirs; the skin, head, feet, lungs, liver, heart, diaphragm, paunch, entrails, and excessive fat are removed, and the carcase goes into the freezing chamber. The heart and diaphragm go to the meat extract and preserved meat department; part of

the entrails goes to the casing department, there to be scoured, scraped, and washed for sausage casings. The main portions of fat go to the oleomargarine department, where it is melted, purified, run into barrels, and slowly cooled so that the stearin separates in large crystals. In this condition it is exported to Great Britain where it is used mainly in the preparation of butter substitutes. The remainder of the animal, including head, feet, paunch, etc., goes to the manure department. Here it is first thrown into a large iron vessel called a digester; a sufficient proportion of blood and water is added, the lid is clamped down, and the whole is digested for several hours under steam at a pressure of 40 lbs. to the sq. inch. This process thoroughly loosens all fleshy material from the bone and disintegrates it. After digestion the liquid is transferred to settling tanks, where the fat rises to the surface, is removed, run into casks, and sent to soap works. The liquid extract, called tankage, which contains 6 or 7 per cent. of highly nitrogenous matter, is run away. Formerly it was wasted, but modern methods enable it to be dealt with very efficiently in a way presently to be described. The solid material from the digester is thoroughly dried, first in a hydraulic press, then in steam-heated cylinders, after which it is ground finely and may be sold as "blood and bone" or animal fertiliser; or, mixed with other ingredients, such as dried blood, phosphates, and potash salts, and diluted or toned down with some suitable material, it is disposed of in the form of various special mixtures. The material used for diluting the mixture, and which is known as a "filler," may be any cheap loose dry substance that does not exercise a deleterious effect on the fertilising constituents; whether it itself has any fertilising properties is a matter of no importance. In America dry sand is used; peat also is an excellent material, maintaining the fertiliser in good mechanical condition. Gypsum has been largely used in this country, but it is expensive. Carbonate of lime is now being used considerably; in some cases it tends to cause the mixture to set hard, and crushing is necessary before bagging. Another consideration is that soluble phosphates are "reverted" and so rendered insoluble in water.

The tankage mentioned above is run into vacuum pans and evaporated under low pressure (4 or 5 lbs. to the sq. inch) until it attains about the consistency of treacle. It is then transferred to a trough into which a large cylinder just dips as it revolves. The cylinder is heated by high-pressure steam inside, so that during its revolution the sticky material gathered as it passes through the trough is dried and removed by a scraper set against the surface. This dried material is called concentrated tankage, and contains 17 or 18 per cent. of nitrogen. As it absorbs moisture from the air very readily it is mixed and ground with about 10 per cent. of its weight of sulphate of iron, which maintains it in good mechanical condition. It is worth more to the manure manufacturer for mixing purposes than it is to the farmer, who seldom requires such a highly concentrated nitrogenous fertiliser.

Dried blood is also prepared in this manner, putting blood alone in the vacuum pan instead of tankage. It contains about 12 per cent. of nitrogen in a readily available form.

As already indicated, these freezing works fertilisers are usually "complete" mixtures, with the additional advantage that the nitrogenous and phosphatic compounds are of various degrees of availability. On the average they contain 1 to 2 per cent. of nitrogen, usually insoluble in water but readily available; 3 to 7 per cent. of water-soluble, and 6 to 12 per cent. of insoluble phosphoric anhydride; and 1 to 2 per cent.

of potash when such is obtainable. It is evident, therefore, that they are essentially phosphatic fertilisers, and this is in keeping with the fact that at present most of our soils exhibit a keener demand for phosphates than for the other constituents.

*Other Proprietary Mixtures.*—Most of the larger firms dealing in manures now sell their special brands of fertilisers blended, as they claim, to suit the various crops, and many of these have acquired considerable local reputation. These mixtures are mainly phosphatic, and differ among themselves chiefly in the presence or absence of one or two per cent. of nitrogen and potash. The nitrogen is derived for the most part from the nitrogenous salts, nitrate of soda and sulphate of ammonia, since the freezing works require most of the blood and bone they produce for their own preparations. Superphosphate provides soluble phosphates, while insoluble kinds are furnished principally by the use of imported rock phosphates and guanos.

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## CHAPTER VIII.

## MISCELLANEOUS FERTILISERS.

1. *Common Salt,* sodium chloride, is a very useful fertiliser for some crops, especially mangels and cabbages. It has some effect on the texture of the soil and its capacity to retain moisture, but its chief action is probably chemical, resulting in the decomposition of potash compounds and the making available of potash. It is also a well-established fact that solutions of common salt are better solvents of phosphates and silicates than pure water. If directly applied to plants in large quantities salt kills them.

2. *Gypsum,* or calcium sulphate, or land plaster (as it is called in America) has already been mentioned in connection with lime compounds. It has been used with good results on clover, its action being no doubt an indirect one, namely, the making available of potash by interaction with insoluble potash compounds in the soil. It was formerly used largely in New Zealand as a "filler" in mixed manures. It is a constituent of superphosphate, being formed in the manufacture of this material.

3. *Ferrous sulphate,* green vitriol, or sulphate of iron is rarely used as a fertiliser, though it is said to be highly effective when used in small quantities, say up to ½ cwt. per acre. In New Zealand it has been found useful, in conjunction with phosphates, in treating "bush-sick" country. (See pages 22, 23, and 46).

4. *Sulphur* has been used at Ruakura Experimental Farm and elsewhere with good results. Sulphur is an essential element of plant food, but it is most probable that plants get all they require of it from its compounds, *e.g.*, calcium sulphate. Its action

when used alone as a fertiliser is doubtless fungicidal and antiseptic, an action that is known to be capable of increasing fertility.

5. *Nitragin* is one of a number of preparations that have been put on the market claiming to be pure cultures of nitrogen-fixing bacteria capable of increase and effective development in the soil. Few of them obtained wide usage, and none of them have survived the test of time.

6. *Humogen* is a preparation invented by Professor Bottomley, of London. It is prepared by the bacterial decomposition of peat after the neutralization of its acids. The material is then sterilised and finally inoculated with a culture of nitrogen-fixing organisms. As a result of careful trials the Rothamsted authorities "find no evidence that humogen possesses any special agricultural value."

7. *Shoddy* includes the waste products, such as shreds and clippings, from cloth mills; it is produced in considerable amount in the milling centres of Great Britain, and has always found a market among the local agriculturists. Wool contains about 17 per cent. of nitrogen in complex combinations, so that shoddy is a slow-acting and long-lasting nitrogenous fertiliser. Its value depends on the proportion of wool in it, since cotton waste has no manurial value. In England shoddy is chiefly used by fruit and hop growers, but it is also useful in the preparation of mixed manures. Its composition is, of course, variable, so that it should be bought on its nitrogen content as disclosed by analysis. The best grades contain 10 to 15 per cent.; the lowest only 2 to 5 per cent.

8. *Leather waste* also contains much nitrogen, but during the process of tanning the nitrogen compounds apparently become quite resistant to the decomposing

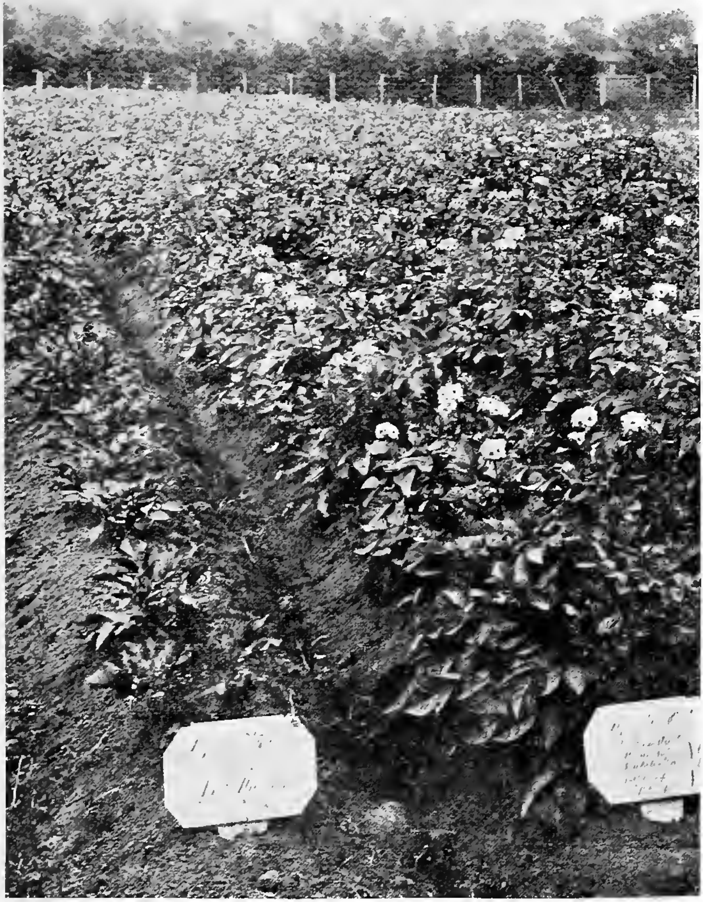
action of soil organisms, so that leather waste has little or no value as a fertiliser. Research work to render the nitrogen available is, however, giving promise of satisfactory results.

9. *Soot* contains some of the nitrogen which is set free when coal is burned. It is therefore a nitrogenous manure, five or six cwt. of which contains as much ammonia as one cwt. of sulphate of ammonia. It has other useful effects, namely a preventive action against slugs and other similar pests, a tendency to improve soil texture, and, in virtue of its colour, a warming effect. It is available only in small quantities in this country, and so finds application only in gardens.

1 cwt. of phosphatic manure is desirable, and if the process is repeated a small amount of nitrogen, such as is contained in a freezing-works' mixture, should also be added. In other cases nitrogenous manures are apt to do more harm than good unless used cautiously, especially in warm moist districts where the crop grows rank and is liable to rust. The use of 1 cwt. of phosphatic fertiliser with all cereals is a practice that is spreading in Canterbury. Barley is best manured through the preceding crop if it is desired to obtain a good malting sample. Peas and beans prefer soil with plenty of lime in it. Basic slag and basic phosphates are suitable manures; nitrogenous fertilisers are quite unnecessary.

*Potatoes.*—This crop pays better than any other for liberal manuring. Farmyard manure should be applied if possible, the whole available supply being reserved for the potato land. Even then artificials should not be stinted, particularly phosphates and nitrogenous compounds. If no dung is available a mixture containing one part sulphate of ammonia, three parts superphosphate, and one part sulphate of potash should be used at the rate of about 3 cwt. to the acre. Blood is a useful substitute for the sulphate of ammonia, and a liberal dose of fresh wood ashes is as good as potash. Kainit is not so good as sulphate of potash, and chloride of potash should not be used at all, as it tends to make the tubers waxy. The following experimental results illustrate the value of a complete manure with this crop on the light soils at Moumahaki:—

| Manure. | Yield. |
|---|---|
| No manure .. .. .. | 6·75 tons |
| 4 cwt. super, 1 cwt. sulphate of ammonia, 1 cwt. sulphate of potash .. .. | 14·8 ,, |
| 4 cwt. super, 1 cwt. sulphate of ammonia | 11·8 ,, |
| 4 cwt. super .. .. .. | 11·6 ,, |
| 4 cwt. super, 1½ cwt. sulphate of potash. | 13·6 ,, |



(*By kind permission of N.Z. Dept. of Agric.*)

Up-to-date potatoes.

No manure.

½ cwt. each of bonedust, basic super, Seychelles guano, and sulphate of potash.

Mr Aston, in the *Journal* (July, 1911, p. 58) cites results of experiments in which the addition of sulphate of potash to a manure containing phosphate and nitrogen caused a further increase in the crop varying from ½ ton to 3·2 tons per acre.

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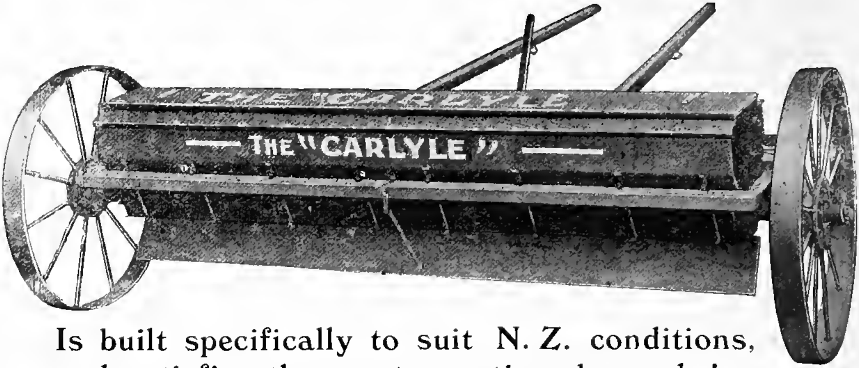

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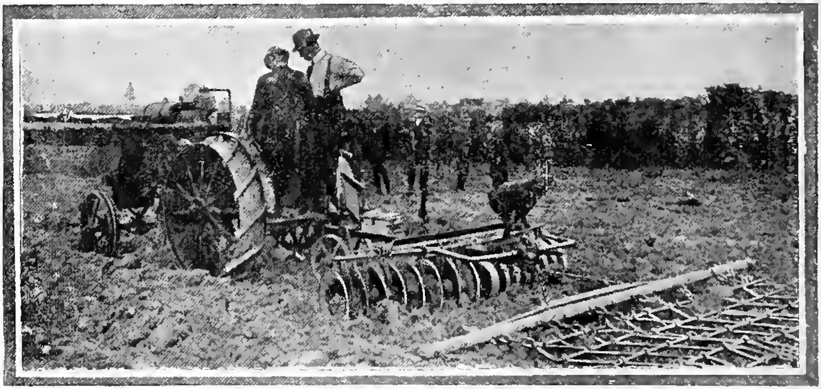

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